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Evaluation of the Policies for Seismic Retrofit of Buildings

Shoichi Ando
International Institute of Seismology and Earthquake Engineering (IISEE), the Building Research Institute (BRI), Tsukuba, Department of Urban Engineering, Graduate School of Engineering, the University of Tokyo, Japan

Abstract: The Japanese government has established a law to promote seismic retrofitting of buildings immediately after the Great Hanshin-Awaji Earthquake in 1995. This paper evaluates the effectiveness, efficiency, administrative feasibility and technological incentives of the policies related to the law. The data shows that the policy target of seismic safety of existing buildings will be achieved in 2018 if the current trends of improvement will be continued. In the field of school buildings, national government supports the school retrofit works that are carried out by the local governments, using the guideline for school retrofit. However, there are still significant issues to make all buildings safe. One of the key challenges is how to persuade the elderly who would not invest their money to improve their old houses. Another challenge is to make owners understand the importance and have priority in improving the seismic safety of buildings. Currently many efforts are taken by the local governments, such as holding seminars for local communities, preparing financial support schemes, providing consultancy for seismic assessment and making earthquake hazard maps. This paper also provides comments on the improvement of the current policies for promoting seismic retrofit based on some international experiences in retrofit of buildings.

Key words: Seismic retrofit, school retrofit, seismic assessment, hazard map, financial support, policy.

1. Introduction

After the Great Hanshin-Awaji Earthquake in 1995, the Japanese government has established around 20 legal systems including the "Act for Promotion of the Earthquake Proof Retrofit of Buildings" (Retrofit Promotion Act) that has been established in 1995 as one of new legal systems. Moreover, many Japanese local governments become to provide various support systems in order to promote seismic retrofit conducted by owners and the private sector. The national government also provides new subsidy systems such as the regional housing grants and the community renovation grants based on the Retrofit Promotion Act. Furthermore a tax reduction system of loans for seismic retrofitting has started from the fiscal year 2006.

Why so many public assistance systems for housing seismic retrofitting exist, though houses are private assets? Originally, this argument arose immediately after the Great Hanshin-Awaji Earthquake. Has the government decided not to appropriate tax revenue (public assistance) for the reconstruction of individual houses, then?

One of the reasons why such a policy change has made, may result from the establishment of the "Act concerning Support for Reconstructing Livelihoods of Disaster Victims" in 1998 and its revision in 2004. This Act is legislation at the instance of house members on the basis of several disasters after the Great Hanshin-Awaji Earthquake. According to this Act, in case of completely or partially destroyed houses, a certain amount of public assistance can be provided to owners of such private assets. For instance, the owner of a completely destroyed house can allow one million yen for purchasing household effects and

Corresponding author: Shoichi Ando, PhD, professor, research fields: urban disaster. E-mail: ando@kenken.go.jp.

two million yen for reconstruction of the house, i.e., in total three million yen will be granted.

In addition, collapse of houses often causes streets blockade and this may bring about crucial obstacles to escape, fire fighting and/or relief activities, when an urban fire occurs as the experience at the Great Kanto Earthquake in 1923 and in Nagata ward of Kobe city at the Great Hanshin-Awaji Earthquake. Namely, seismic retrofitting of buildings including house, is indispensable in order to secure entire urban safety. Therefore, public assistance can be provided, even though houses are private assets.

Taking a view of the estimated tolls by the Tokai Earthquake published by the Cabinet Secretary in 2005 as a reference, the maximum number of death toll will reach to approximately 9,200 persons by the assumed ocean-type Tokai Earthquake. And around 85% of death toll, i.e., approximately 7,900 dead persons will be due to the collapse of buildings and like. At the same time, the Japanese Cabinet Secretary announced a target to reduce those tolls by half in the "Earthquake Disaster Mitigation Strategy" for Tokai Earthquake. For that purpose, a detailed target to improve housing seismic retrofitting ratio was set up from current 75% to 90% within 10 years (till 2015). The "Earthquake Disaster Mitigation Strategy" was also created for coming Tohnankai and Nankai (South-east Ocean and South Ocean) Earthquake in 2005 and the main targets consist of housing seismic retrofit and tsunami disaster prevention measures.

These are the backgrounds of movement that many actors established new supporting measures for housing seismic retrofit in all parts of Japan from the establishment of the Strategy in 2005 till now.

2. Retrofit Systems in Japan

2.1 Technical Background

"The 1995 Great Hanshin-Awaji Earthquake disaster revealed the weakness of reinforced concrete (RC) structures that were designed in accordance with the pre-1981 design code. Failure of RC columns was primarily in the lack of lateral reinforcement. Larger deformation capacity may be attained by enhancing the capacity by

(a) Jacketing RC columns with steel plates and

(b) Wrapping RC columns with fiber reinforced plastics (FRP).

The use of FRP sheets has merit of easy construction work and of light material weight. Placement of bracing structures (structural walls or steel braces) is effective limiting the response deformation of the structure, thus avoiding the failure of brittle members.

The occupancy of a building during the retrofit work should be considered in selecting retrofit works. For example, the strengthening work of RC columns normally requires the removal of mortar and other finishing materials (tiles) from the concrete surface. The noise, vibration and dust during the retrofit work will not allow occupants to stay in the building.

If advanced technology is affordable, especially in hospitals for post-earthquake medical treatment of the injured, the earthquake induced forces may be reduced by placing isolation devices at the base. The response of a structure may be reduced by installing dampers or energy dissipating devices are available. The failure of foundation piles was reported after the 1995 Kobe earthquake disaster. In some structures, the failure of pile foundation is said to reduce the earthquake ground motion input to the structure and limit the damage in the super-structure. However, the cost of damage investigation of foundation as well as the repair work of damaged foundation is expensive. It is normally desired to provide the foundation structure with higher resistance". [1]

The need of retrofit relates to the revision of building code especially up-grade of seismic code. If building code revised in 2005 and as shown in Fig. 1, when small portion of building follow new code, there is not so much demand of retrofit of old buildings. However when large portion of building stock follow the new code, owners of existing building may require retrofit. (by Prof. Shunsuke Otani)

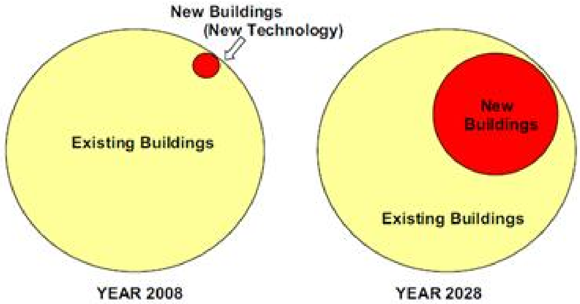

Fig. 1 Relation of Design Code for New Construction [2].

2.2 Retrofit Promotion Act and Its Support Systems

The Retrofit Promotion Act was enforced in 1995 immediately after the Great Hanshin-Awaji Earthquake in January 1995, since the lessons learnt from the devastated disaster urged quick response of the government and policy makers to secure the safety of urban built-environment that are mainly consisted of houses and buildings. Key components of the new Act are:

- Obligation of owners to make best efforts to assess and retrofit the buildings that are utilized many people;
- Exemption of retroactive application of building code except for seismic related code to approved retrofit works;
- Guidance, advices and instructions from the responsible governmental agency.

With regard to new obligation for the owners of building that is utilized by many people, such building is defined as, more than 3 stories and more than 1,000 m2 of floor area and its use is in line with designated one such as school, hospital, department store, office, shop, hotel, care facility for the elderly and so on.

When the Retrofit Promotion Act was established, the Japanese Ministry of Land, Infrastructure, Transport and Tourism (MLIT) surveyed the conditions of houses and buildings in terms of applicability to seismic code (in 1981, the current level of seismic safety). The updated result of the survey is indicated in the Table 1. The target of applicable level of seismic code is also shown in the Fig. 2.

Table 1 Numbers of buildings under (1981) seismic code level.

Houses	
	Total houses in Japan
Total numbers of houses	47 million units
Under seismic code units	11.5 million units
(percentage of under level)	Around 25%
Estimated based on the data in 2003	
Non-residential Building	
Total number	3.4 million buildings
Under seismic code units	1.2 million buildings
(Percentage of under level)	Around 35%
Estimated by the Ministry of Land, Infrastructure, Transport and Tourism in 2002.	

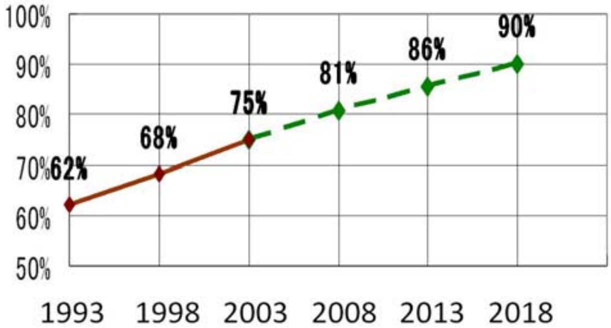

Fig. 2 Trend estimation of safe houses (seismic code) (Estimated by the Ministry of Land, Infrastructure, Transport and Tourism in 2003).

The Act was established to introduce retrofit of houses and buildings. Therefore, in addition to regulatory measures some economic measures have been prepared at the same time by the national government. Those economic measures are available only in the local government that established "Plan for Retrofit Promotion". Table 2 shows the number and ratio of the local governments that have established the Plan for Retrofit Promotion. Table 3 shows the number and percentage of the municipalities that have prepared the subsidy systems for seismic assessment and retrofitting.

Those tables show the fact that even in 2009, one quarter (25%) of municipalities have prepared the subsidy system for condominium to assess/evaluate the vulnerability to earthquake. In case of detached houses, almost 2/3 of municipalities have established subsidy system by 2009 for assessment and almost half of them have prepared financial support for retrofitting of houses. Figures of the Table 3 in the entre- parenthesis indicate the number of percentage of the April 2008.

Within only one year, the percentage has been significantly improved because of the following policy measures, while a limit of financial support to the retrofit can be observed especially in the field of condominium and non- residential buildings.

The following policies are described as the MLIT has reported as below;

(1) Formulation of municipal Retrofit Promotion Plans;

(2) Establishment of prefectural/municipal subsidy system;

(3) Promotion of retrofitting of public buildings;

(4) Securing engineers who manage assessment/ retrofit;

(5) Utilization of tax incentives for business use buildings;

(6) Preparation of seismic hazard mapping;

(7) Best practices for seismic assessment/retrofit;

Table 2 Number of Local Governments that have retrofit promotion plans (as of 1 April 2009).

	Have plans	-2009.9	-2010.3	-2010.4
Prefecture	47			
Total (%)	47			
	100.0%			
Municipality	1.193	50	185	70
Toal (%)	1.193	1.243	1.428	1.428
	66.3%	69.1%	79.3%	83.2%

Table 3 Subsidy system for seismic assessment and retrofit (as of April 2009, Japan).

Building type	Project type	Applicable local Govt. for reftrofit subsidy	
		Number of local Govt.	Ratio: Applicable Govt.
Detached house	Assessment	1,227	68.2% (62.7%)
	Retrofitting	857	47.6% (37.2%)
Condominium	Assessmen	450	25.0% (19.0%)
	Retrofitting	321	17.8% (12.1%)
Non-residential	Assessmen	310	17.2% (13.2)
	Retrofitting	154	8.6% (5.9%)

(8) Model projects on seismic safety houses and buildings.

Those measures are comprehensive. Socio-economic measures, information measures, technical measures, and institutional measures are included to promote the policy for seismic assessment and retrofit of buildings. [3]

2.3 Retrofit of Schools in Japan

"Because of the Great Hanshin-Awaji Earthquake in 1995, school buildings were also severely damaged by the shake." [4] According to a report provided by the Ministry of Education, Culture, Sports, Science & Technology (MEXT), approximately 4,500 educational facilities were structurally or non-structurally damaged, though there were fortunately no death tolls resulted from damaged schools since the Great Hanshin-Awaji Earthquake occurred in early morning at 5:46 a.m.. After the strike of the Earthquake, 390 schools took the role for evacuation shelter and these schools accommodated approximately 180,000 evacuated people.

Furthermore, at the time of recent major earthquakes such as Niigata-Chuetsu Earthquake in October 2004 and Iwate-Miyagi Nairiku Earthquake in June 2008, while many school buildings were damaged, non-damaged schools accommodated many evacuated people. On the basis of these experiences, it is critical to ensure that school students are safe and school facilities are fit to serve as evacuation shelters for local populations. MEXT's policies on structural and nonstructural retrofitting of school buildings are introduced. Since school buildings have the following crucial roles, it is indispensable to assure the safety of school buildings against earthquakes.

(1) Place for educating children: school buildings are the place where many children study and live most part of their days. It is, therefore, vital to keep school buildings in safer and healthier environment.

(2) Place for cultural and sporting activities: school is a well-known building to the people who live near the school. School buildings are, therefore, often

utilized for the cultural and sporting events for the local population.

(3) Place for evacuation: school often becomes an evacuation shelter when a major natural disaster occurs. To this end, it is important that school buildings accommodate necessary functions for evacuation shelter.

The Building Standard Law of Japan was revised in 1981 and new seismic resistant design methods were adopted. According to the revised law, the buildings constructed based on the new design would have no damage in the case of middle class earthquakes (about JMA 5 upper scale). Moreover, there would be no casualties in these buildings and no severe collapse of these buildings even in the case of major earthquakes (about JMA 6 upper) (Table 4).

In order to evaluate the seismic capacity of an existing school building, the seismic capacity index of structure (Is) is used in Japan based on the regulation of the Retrofit Promotion Act. The law regulates that a building has low risk of collapsing if the "Is" of the building is more than 0.6. However, in consideration of the importance of school building, MEXT recommends that the "Is" of school building should surpass 0.7 after retrofitting.

Is (Seismic Capacity Index of Structure) (Table 5): An index to define the seismic capacity of an existing reinforced concrete building

$$Is = Eo \times S \times T$$

Eo: A basic structural seismic capacity index calculated by the elements of Strength index (C), Ductility index (F) and Story Index (St)

$$Eo = C \times F \times St$$

S: A reduction factor to modify **Eo** index, which is based on the structural balance in both plan and elevation.

T: A reduction factor to modify **Eo** index, which is graded by time-dependent deterioration.

A survey carried out by MEXT in April 2002 showed that public school buildings had not been satisfactorily retrofitted. It emerged from the 2002 survey that seismic assessment/diagnosis was carried

Table 4 Difference between new and old seismic resistant design.

Type of earthquake (JMA scale)	Medium scale earthquake (about 5 upper)	Larger scale earthquake (over 6 upper)
Old seismic resistant design (until 1981)	No major damage	Not verified
New seismic	No major damage	Will not collapse

JMA Scale: Scale indicating the strength of seismic motion, which was formed by JMA (Japan Meteorology Agency);
5 Upper: Many people are considerably frightened and find it difficult to move;
6 Upper: Impossible to keep standing and to move without crawling.

Table 5 Seismic capacity index of structure (Is).

Is < 0.3	There is high risk of collapsing
0.3 < Is < 0.6	There is risk of collapsing
0.6 < Is	There is low risk of collapsing

out on only 30% of buildings built based on the pre-1981 Old Seismic Resistant Design, and only about 45% of public primary and junior high school buildings had been retrofitted.

In this connection, a council called "Co-operators' Meeting for the Survey and Study of the Promotion of Earthquake-Resistant School Buildings" was established by MEXT in October 2002. The outcomes of the council's discussions were submitted to MEXT in April 2003 in a report entitled the "Promotion of Earthquake-Resistant School Buildings". Based on this report, the "Guidelines for the Promotion of Earthquake-Resistant School Buildings" was stipulated by MEXT in July 2003.

Chapter 1 of this guideline describes the basic concept of the "earthquake-resistant school building" and Chapter 2 outlines the methods for devising earthquake-resistant promotion plans, the points to bear in mind, and the suggested methods for determining the urgency of earthquake resistance projects.

The basic principles pointed out in this guideline are:

(1) to prioritize earthquake resistant measures for school buildings at high risk of collapse or severe

damage; (2) to implement seismic resistant capacity evaluation promptly; (3) to develop a plan for promoting earthquake resistance promptly; (4) to disclose the results of the seismic resistant capacity evaluation and the plans for promoting earthquake resistance; and (5) to check and take measures for the earthquake resistance of non-structural elements. [5]

MEXT has been urging municipal governments, which are responsible for school buildings, to promote school building's retrofitting based on the above-mentioned guideline. In addition, as the following figure shows, MEXT has a subsidy system regarding public school buildings (Table 2). In line with the Sichuan Earthquake in China in May 2008, MEXT has raised the subsidy rate for vulnerable school buildings (Is < 0.3) from a half to two thirds in June 2008.

By utilizing the above-mentioned subsidy system, the retrofitting of school buildings has been implemented in Japan. The data shows the status of earthquake resistance on elementary and lower secondary public schools in Japan as of April 1, 2008. Approximately 48,000 of school buildings, or 38% of school buildings were found lacking needed earthquake resistance or needed further assessment. Above all, 10,000 of these buildings were estimated to be at high risk of collapse in expected large scale earthquakes. A commitment was made to reinforce all of these buildings at high risk within 5 years. In addition, as mentioned, the subsidy rate for vulnerable school buildings has been raised in June 2008. Moreover, in order to accelerate the 5 years retrofitting program into 4 years, MEXT has added an additional national fund (114 billion JPY) to the regular budget of fiscal 2008 (115 billion JPY, total 229 billion JPY) in the supplementary budget of fiscal 2008 of Japanese government in October 2008 based on the Table 6.

Even though structural parts of school buildings such as columns, beams and walls are enough retrofitted, if non-structural members such as ceiling

Table 6 Subsidy rate for public school building.

Type of construction	Subsidy rate from MEXT
New construction	1/2
Reconstruction	1/3. 1/2 (Is < 0.3)
Renovation	1/3
Seismic rehabilitation	1/3, 1/2 (Is < 0.3)

Budget of fiscial 2008:229 billion JPY.

materials, various fixtures and furniture are not sufficiently retrofitted, these non-structural members may fall or topple when a major earthquake occurs. Children and evacuated local people can be killed or injured by these vulnerable non-structural members. Therefore, the retrofitting of non-structural members of school building is extremely important.

In order to urge municipalities to implement non-structural seismic retrofitting of school buildings, the National Institute for Educational Policy Research of Japan (NIER) published a reference book on non-structural seismic retrofitting of school building in December 2005.

The following case is an example in this reference book. [6]

3. Issues of Retrofit Works

3.1 Technical Issues [7]

It should be noted that these countermeasures may not be the same from a country to another because the expected performance (minimum required strength and acceptable damage) of buildings varies from a country to another. Each country has different levels of

(a) Seismic risk,
(b) Hazard tolerance,
(c) Economic background, and
(d) Technical development (construction practices).

Most building codes in the world explicitly or implicitly accept structural damage to occur in a building during strong earthquakes as long as the hazard to life is prevented. Indeed, many earthquakes caused such damage in the past. Then, what percentage of buildings suffered heavy damage in major earthquakes. The Architectural Institute of Japan (AIJ) collected damage statistics in Mexico City and Lazaro Cardenas after the 1985 Mexico Earthquake, Baguio after the 1990 Luzon, Philippines Earthquake, Erzincan after the 1992 Turkey Earthquake, and Kobe after the Hyogo-ken Nambu 1995 (Great Hanshin-Awaji) Earthquake. A heavily damaged area was first identified in each city, and the damage level of all buildings in the identified area was assessed by structural engineers and researchers.

From damage statistics (Table 7 and Fig. 3), the importance of identifying the small percentage of those buildings possibly vulnerable in future earthquakes can be easily realized. Therefore a simple procedure is desirable to examine the vulnerability of all existing buildings in a region, spending a few hours at most for a building, and “screen out” the majority of safe buildings. A more detailed and sophisticated procedure, spending a few weeks, may be utilized to those buildings identified as vulnerable by the simple procedure.

Table 7 Damage Statistics from Major Earthquakes [8].

City, year of earthquake	Operational damage	Heavy damage	Collapse	Total
Mexico City, 1985	4251 (93.8%)	194 (4.3%)	87 (1.9%)	4.532
Lazaro Cardenas, Mexico, 1985	137 (83.5%)	25 (15.2%)	2 (1.2%)	164
Baguio City, Phillippines, 1990	138 (76.2%)	34 (18.8%)	9 (5.0%)	181
Erzincan City, Turkey, 1992	328 (77.4%)	68 (16.8%)	28 (6.6%)	424
Kobe (pre-1981 construction), 1995	1186 (79.4%)	149 (10.0%)	158 (10.6%)	1493
Kobe (post-1982 construction), 1995	1733 (94.0%)	73 (4.0%)	38 (2.1%)	1844

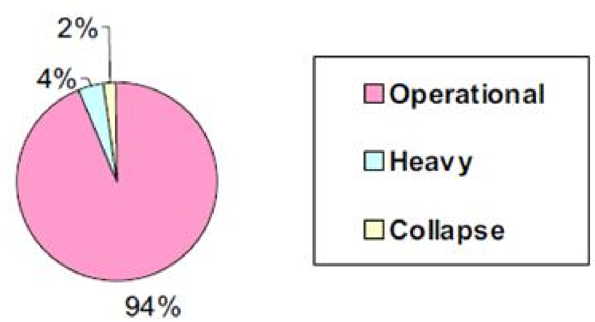

Fig. 3 Damage distribution of Mexico City.

In a screening procedure, for example, dimensions of columns and structural walls per floor areas may be used to roughly estimate lateral load resistance. The lateral load strength is not a single index to represent the safety of a building, but gives some idea if the structure has a sufficient capacity to resist earthquake motions by strength. Those buildings, identified as questionable by the simple procedure, must be analyzed by more sophisticated procedure

The following development and application of technology are needed to mitigate earthquake disaster from construction point of view: i.e.:

(a) Effective earthquake resistant building codes for new construction,

(b) Earthquake vulnerability assessment methods for existing buildings,

(c) Seismic strengthening technology for vulnerable buildings,

(d) Seismic damage evaluation methods for damaged buildings after an earthquake,

(e) Technology to repair damage for immediate occupancy, and

(f) Technology to rehabilitate damaged buildings for permanent use.

3.2 Socio-Economic Issues

An examination of allocation of government resources, in terms of financial and human, for pre-disaster and post-disaster disaster programs reveals that more resources are devoted recovery than to disaster prevention. They commit a large amount of financial and human support after a disaster. This is particularly true for the international community. Disaster prevention programs attract little attention. However, because emergency operations take place after a disaster when many lives have already been lost, only few lives can be saved. In contrast, the implementation of disaster preventative measures can potentially save many more lives.

Hence, we must shift our done on seismic resistance and isolation technologies of high rise buildings, but little research is done on conventional houses. But over 80% of total stock in the world is non-engineered. Because these unsafe buildings are occupied by humans, we cannot reduce disaster losses unless we improve the safety of non-engineered buildings (in case of Japan, wooden houses). However, they attract little attention and research funds. Similarly, when spending habits for new and existing houses are compared, people tend to spend generously for new houses but not as much for the maintenance. However, many more lives can be saved by improving the safety of existing houses.

Another essential aspect is cost reduction. There are several ways to achieve this, for instance, technological development and government subsidies. It is also necessary to train masons and carpenters on available techniques.

The political commitment is also crucial. The rea1493son is that many individual house owners would pay to reinforce their houses if they understand the need; but not all house owners would. Everybody dies eventually. Considering this, the probability of death from an earthquake, which chance of occurrence is 40 percent in every 30 years, might seem negligible. Just like the fact that many smokers wouldn’t stop smoking even if they are told to do so, not all individual house owners would reinforce their houses. [9]

One of the key challenges is how to persuade the elderly who would not invest their money to improve their old houses. Another challenge is to make the housewives understand the importance and have priority in improving the seismic safety of houses.

4. Retrofit Examples in the World

This section shows four retrofitting examples in the world. In addition to the cases in Japan, the author had relation with some retrofitting cases in Nepal, Indonesia, Uzbekistan and China through projects at the UNCRD Hyogo Office and the Building Research Institute (BRI).

4.1 Example 1 (Houses in Nepal)

Nepal faces a variety of disaster risks owning both to its natural characteristics and human induced factors. Nepal has experienced several major earthquakes: The Bihar Earthquake in 1934 which measured 8.3 on the Richter scale killed 4,300 people, and destroyed 20% of all structures (Earthquake and Megacities Initiatives, 2005). Three earthquakes of similar size occurred in Kathmandu Valley in the 19th century: in 1810, 1833, and 1866. In 1988, there was another earthquake, which caused to loss of 709 lives (The National Society for Earthquake Technology NSET- Nepal).

United Nations Centre for Regional Development (UNCRD) has carried out a training project in Nepal in 2007. The training was organized with technical support from NSET to train practical measures that can be applied at the house level. 20 female members from target communities participated in the training. In the workshop, they learnt the basic science of earthquakes, importance of disaster risk reduction, and how to apply non-structural risk mitigation measures in their homes. For example, they visited several houses to learn practical ways of securing refrigerators and shelves by using brackets and props.

After the initial training, follow-up evaluation meetings were held with the participants. 19 participants reported that they have applied non-structural measurements in their homes within one or two weeks after the training by themselves (13 people) and/or with male members in the family (16 people), while there was one person who hired a handyman. 17 participants reported having talked about the training with relatives and/or friends, and 15 participants had showed their relatives and/or friends what they had done in their homes to secure their furniture.

Furthermore, 14 participants answered that they know relatives/friends who have implemented such non-structural risk reduction measures in their homes after observing their examples. The result showed that there was a strong potential for using women's network and communication to disseminate disaster risk reduction strategy. [10]

Though the project has not aimed at retrofitting itself, fixture of nonstructural part of a house is recognized as the first step to raise awareness of community people, especially for housewives who must play an important role as decision makers for house maintenance. And this case study shows the communication network among housewives effectively works to disseminate the seismic measures for houses like fixture of furniture (as shown in Fig. 4 and Fig. 5).

4.2 Example 2 (Schools of Indonesia)

Earthquakes in the past have exposed that

Fig. 4 Household assessment of non-structural part (NSET).

Fig. 5 A trainer of NSET secures furniture using anchors in a community participant's home in Kathmandu (by UNCRD).

vulnerability of school buildings is disproportionately high compared to the other infrastructures. For instance, in the 1999 Chi-Chi Earthquake, Taiwan 43 schools in Nantou and Taichung area were completely destroyed and a total of 700 schools nationwide were damaged to different extent. The 2001 Gujarat Earthquake in India caused damages to over 11,600 schools. The 2005 Kashmir earthquake resulted in collapse of 6,700 schools in North-West Frontier Province and 1,300 in Pakistan-administered Kashmir [11]. Recently in May 2008, Wenchuan Earthquake in China killed about 7,000 students trapped in damaged school buildings. When an earthquake hit Spitak area of Northern Armenia during school hours in 1988, many children lost their lives due to collapse of school buildings. For example, 285 children out of 302 in total died at one school. This resulted in almost 2/3 of total deaths of 25,000 were children and adolescents.

UNCRD and the Center for Disaster Mitigation (CDM) of the Institute of Technology Bandung (ITB) conducted a collaborative project to reduce the vulnerability of existing school buildings in the corridor of the School Earthquake Safety Initiative (SESI) project. Two school buildings, SD Cirateun Kulon II and SD Padasuka II both in Bandung County, were selected for this project due to the dire needs of improvement and severe deficiencies of earthquake resistant systems. The project included retrofitting and strengthening of school buildings, and other activities to improve school community preparedness regarding earthquake.

Prior to conducting any physical work to the structure, the locations and building layouts were checked to ensure that the buildings could be retrofitted. The existing structures were investigated to determine the type and quality of materials used, as well as the existing lateral resisting system. Then, the retrofitting was designed based on the structural deficiencies/weak parts and their accessibilities, weighing in retrofit factors on buildings' life time, earthquake resistance capacity, their function, and appropriate retrofit strategy/ techniques. The design of retrofit strategy also considered factors of continuation of normal function, availability of materials and skilled construction workers, needs of upgrades for non structural components, and total costs.

The retrofitting project was first conducted at the school SD Cirateun Kulon II. The school buildings consisted of two buildings made of RC frames and masonry walls. Each building has four rooms. Based on results from survey and tests, structural analyses were performed on the existing structures using the actual material and structural components. Earthquake risks were introduced to the buildings by applying loads based on potential seismic risks and local soil conditions. The analysis showed that both buildings were considered likely to behave poorly under seismic loadings, thus required retrofitting. The physical works were then conducted to improve the structural quality and reduce the earthquake vulnerability.

Building I which was considered to have lower quality was retrofitted by adding adequate RC frames with mat footings. Anchorage was provided to connect walls with columns and beams. Building II which was in better condition was retrofitted using wire mesh for strengthening wall elements (as shown in Fig. 6). Double tie beams were added adjacent to the existing one for better foundation system. For both structures, proper detailing was applied to roof truss systems, and repair was carried out for nonstructural elements such as doors/windows and ceilings. Finishing/cosmetic repair and improvement of sanitary facilities were also conducted for both structures.

Fig. 6 Retrofit work of School Building I (ITB).

4.3 Example 3 (Schools of Uzbekistan)

In Tashkent city, there are more than 360 schools. Nearly 20% of school buildings have had deficiencies of different level at present. Preliminary analysis of seismic risk for Tashkent city showed that more than 25% of school buildings may be completely destroyed and 30% may be heavily damaged in case of design earthquake.

The buildings of schools in Tashkent are represented mainly by two construction systems: bricks and RC frame-panel consisting major portion of school building stock and a few buildings made up of from adobe bricks. Nearly 35% of school buildings were constructed before Tashkent earthquake of 1966 for design intensity 7 by MSK scale. Since 1966, half of school buildings were constructed using assembled RC frames of IIS-04, which are inherently weak in seismic resistance. The weakness of this construction type was revealed Spitak (1988), Kairakkum earthquakes (1985) and also confirmed by through the engineering analysis of earthquake consequences.

Many school buildings in Tashkent are located in the zone with slumping soils, and as a result many buildings, both brick walled and frame panel type are likely to be damaged. The survey showed that typical structures used for school building in Tashkent basically consist of brick works up to 4 stories in old construction, and reinforced concrete frame-panel for the more recent buildings (as shown in Fig. 7). Recurrent structure typologies for school buildings are categorized in the following three groups:

(1) Mixed type of brickwork and reinforced concrete or wood reinforcing frame — year of construction ’40s;

(2) Brickwork structures, frequent typology used until 60s;

Fig. 7 Retrofit of RC panel school in Tashkent (UNCRD).

(3) Frame-panel, widely used in the modern construction.

In order to establish an effective and recognizable linkage to the local professional practice in the Central Asian region, and to follow the standard analysis procedure, it is ensured that the characterization is in compliance with the previous study on the Risk Assessment of Tashkent city in the framework of IDNDR RADIUS project in 1990's. [12]

4.4 Example 4 (Buildings of China)

Ministry of Housing and Urban-Rural Development of People's Republic of China (MOHURD) has held several investigations on the disaster after the Wenchuan Earthquake. Upon the analysis and research, MOHURD has constituted "Technical Guide for Appraiser and Strengthening of Earthquake Affected Buildings" on July 23rd, 2008, and promptly issued "Seismic Technical Specification for Building Construction in Town and Village" on June 13th, 2008, and implemented on October 1st, 2008.

The Chinese "Standard for Classification of Seismic Protection of Building Constructions" GB50223-2008 has been enacted on July 30th, 2008. It has been partially amended on the original "Standard for Classification of Seismic Protection of Building Constructions" GB50223-2004. In addition, "Code for Seismic Design of Buildings" GB50011-2008 (enacted on July 30th, 2008) has been amended on the original "Code for Seismic Design of Buildings" GB50011-2001.

Wenchuan earthquake provided abundant experiences for seismic project constructions. In order to improve the capability of disaster area's reconstruction and Chinese project construction disaster-prevention, MOHURD and experts from relevant departments have researched and analyzed earthquake experiences, and have summed up the seismic engineering research results.

On the above amendments, MOHURD has adjusted some seismic standard, especially enhancing the public building seismic standard on secondary & primary schools and hospitals, extending the seismic prevention scope of public seismic buildings including retrofitting works. Besides, MOHURD has also amended the design code and criteria from the aspects of specific technologies.

To learn from Japan's accumulated seismic building technology and further promote the application of seismic technology, to improve the capability of earthquake and hazardous prevention, and to increase the technical level in China, Financing & Foreign Affairs Dept. of MOHURD and Japan International Cooperation Agency (JICA) has reached an agreement on the "China-Japan Seismic Training Program" on May 12th, 2009. This program will last 3 years and be fully supported by Ministry of Land, Infrastructure, Transport and Tourism (MLIT) of Japan.

The International Institute of Seismology and Earthquake Engineering (IISEE) of the Building Research Institute (BRI), Tsukuba, Japan is the implementing agency of the training on assessment, retrofit and design for seismic building since 2009.

5. Conclusions

The Japanese government has established a law to promote seismic retrofitting of buildings immediately after the Great Hanshin-Awaji Earthquake in 1995. This paper evaluates the policies related to the Retrofit Promotion Act. The data shows that the policy target of seismic safety of buildings (90% of buildings follow the 1981 seismic code) will be achieved in 2015–2018 if the current trends of improvement will be continued. In the field of school buildings, national government supports the school retrofit works that are carried out by the local governments, using the guideline for school retrofit.

However, there are still significant issues to make all houses safe. One of the key challenges is how to persuade the elderly who would not invest their money to improve their old houses. Another challenge is to make the housewives understand the importance and have priority in improving the seismic safety of houses.

Currently many efforts are taken by the Japanese local governments, such as holding seminars for communities, preparing financial support schemes, providing consultancy for seismic assessment and making earthquake hazard maps. This paper also provides comments on the improvement of the current policies for promoting seismic retrofit based on some international experiences of house and building retrofit. Some international cases will help to develop an effective Japanese policy for promoting retrofit, such as the case of Nepal shows the role of females to disseminate the seismic safety of non-structural part of houses.

The Japanese experiences on seismic retrofit will be able to contribute to the disaster risk reduction in the other seismic-prone countries in the world. The lessons from Kobe and lessons from all over the world should be disseminated to find solutions towards challenges to promote policies and actions of seismic assessment and retrofitting.

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Sustainability Impact on Construction Management in Developing Countries: Iraq as a Case Study

Basil Kasim Mohamed
School of Civil and Construction Engineering, Oregon State University, USA

Abstract: Sustainable development contributes to the economic and social advancement of construction projects. Ignoring sustainability during the cost estimating process associated with evaluation phase develops many problems of conventional decision methodology used in construction industry in the most of developing countries. This research focuses on sustainability which is the key factor in all decision making in design and construction processes. Therefore, Iraqi construction industry should respond to sustainability as a leading indicator of its infrastructure rebuilding. The construction management and sustainability could help to manage the rebuilding of the destroyed public infrastructure during the disaster wars periods passed thru thirty years ago and also to modernize of private buildings and plants. Field study has been carried out by adopting personal interviews and questionnaires conducted with experts, experienced consultants and designers working in many design organizations. The data collected has been analyzed and the results obtained show a clear weakness in the field of sustainability understanding, practicing and implementation. Moreover, the design work in Iraq is suffering from a lack of scientific techniques and a lack in experience in the domain of sustainability field. This will take an integrated approach to study the impact of sustainability on construction management which encompasses both public and private sector perspectives for building and engineering construction, and the roles played by all the participants in the construction team (owners, contractors, design professionals, and other supporting professionals).

Key words: Sustainability concepts, construction, management, engineering, developing countries, Iraq.

1. Introduction

Sustainability is defined by the ISO 15392 international standard as the state in which components of the ecosystem and their functions are maintained for the present and future generations (ISO Standard 2008). Buildings and structures enabled mankind to meet their social needs for shelter, to meet economic needs for investment and to satisfy corporate objectives. However, the satisfaction of these needs usually comes with a high price, i.e., an irreversible damage to our environment. This lead to a growing realization around the world to alter or improve the conventional way of development into a more responsible approach which can satisfy the needs for development without harming the world we live in.

Corresponding author: Basil Kasim Mohamed, PhD, professor, research fields: project management, quality management systems, sustainability practices, engineering education. E-mail: basilkasim555@yahoo.com.

The ideas and strategies initiated by these world events have prompted positive actions and plans by many countries to implement this approach in their industries. Delivering sustainable construction requires action from all engaged in constructing and maintaining the structure or building including those providing design, consulting and construction services [1]. It requires willingness to explore new fields in construction approach and prepare to adopt new ideas and practices [2]. As global interest on sustainability has steadily blooming, developing countries should not fell short in its attitude on sustainability and sustainable construction.

The concept of sustainability in building construction has evolved over many years. The housing is now universally recognized as a human right and that effort to implement this right must be strengthened and accelerated in the developing countries. Sustainability in construction is not clearly recognized in most of developing countries included Iraq. The success and progress of human society depends on physical infrastructure, and a nation's economic strength is reflected in its infrastructure assets [3]. The traditional design process and construction in these countries focuses only on cost, quality and time, while environmental objective could add to these criteria minimization of resource depletion, reducing harmful emissions and maintaining a healthy environment together with conserving natural areas and biodiversity. That can be shown in Fig. 1 as a new paradigm to construction. In addition, economic, social and cultural dimensions of sustainability become very present especially in the global context [4].

2. Sustainability in Construction

The concept of sustainability in construction has initially focused on issues of limited resources especially energy, and on how to reduce impacts on the natural environment with emphasis on technical issues such as materials, building components, construction technologies and energy related design methods. The appreciation of the significance of non-technical issues has grown, giving recognition to economic and social sustainability concerns as well as cultural heritage of the built environment as equally important [5, 6].

Sustainable construction could be defined as a construction process which incorporates the basic themes of sustainable development. Such construction processes would thus bring environmental responsibility, social awareness, and economic profitability objectives to the fore in the pre project evaluation of built environment assets [7]. The green building movement is gaining momentum around the world. One of the biggest challenges facing contractors, designers and planners is how to ensure that our cities are developed and regenerated to be sustainable for the future. Building and construction companies in both public and private sectors should encourage the adoption of sustainable and environmental policies and practices yet there is evidence that in general it is a concept that is still misunderstood and unsupported by many project owners [8].

Sustainable construction is a process whereby, over time, sustainability is achieved. Sustainability should be applied into construction industry to influence the manner in which a project could be conducted to strike a balance between conserving the environment and maintaining prosperity in development. Attaining sustainability does not mean the eradication of adverse impact, which is an impossible vision at present, but rather the reduction of it to a certain reasonable level [2].

The direction of the construction industry is now shifting from developing with environmental concern as a small part of the process into having the development process being integrated within the wider

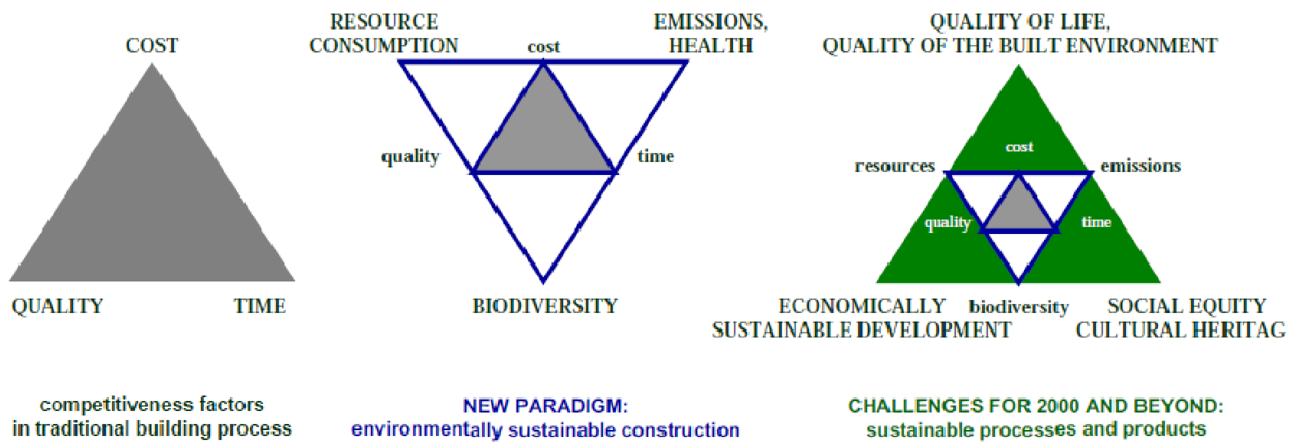


Fig. 1 Sustainability new approaches [4]

context of environmental agenda. Thus, the activities of construction industry should work and comply with the needs to protect and sustain the environment.

Previously, the concern on environment is relatively a small part of most of construction development. However, with the growing awareness on environmental protection due to the depletion of nonrenewable resources, global warming and extremity of destruction to ecology and biodiversity impact, this issue have gain wider attention by the construction practitioners worldwide. The direction of the construction industry is now shifting from developing with environmental concern as a small part of the process into having the development process being integrated within the wider context of environmental agenda. Thus, the activities of construction industry must comply with the needs to protect and sustain the environment [9].

Presently, the concept of sustainable construction governs three main pillars: environmental protection, social well-being and economic prosperity. Fig. 2 shows the tree diagram of these three headings and their areas of concern [10] where it covers the main sustainability aspects as indicated in the international standard ISO 15392, and ISO 16813. Environmental protection concerns on the built environment and the natural environment. The built environment refers to the activities within the construction project itself, which may, if not handled effectively, have a serious adverse impact on the environment. Environmental sustainability is also concerned with the extraction of natural resources. Although builders have little influence over the extraction of natural resources, they can help discourage this activity by demanding less

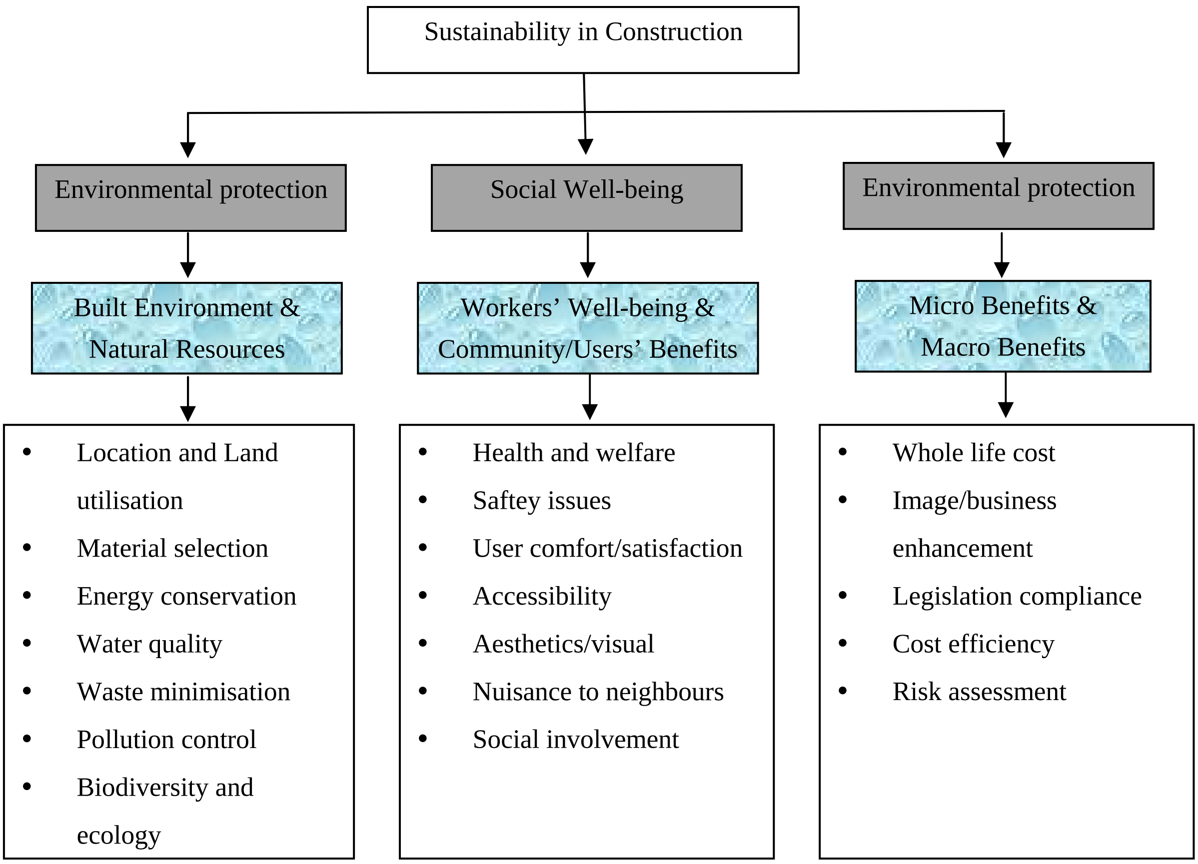


Fig. 2 The diagram of sustainability in construction [10].

non-renewable natural resources, more recycled materials, and efficient use of energy and mineral resources [11]. Social well-being concerns with the benefits of the workers and the future users. Basically, this aspect is concerned with human feelings: security, satisfaction, safety and comfort and human contributions: skills, health, knowledge and motivation [12].

3. Infrastructure Reconstruction Problems in Iraq

After the war 2003 in Iraq the infrastructure has been largely destroyed (about 70%) roads, bridges, oil refineries, gasoline storage tanks, electric power plants, health and educational institutes, industrial facilities, public and residential buildings, communication system, even village water tanks. After the war's end, only 20% of Iraq's pre-war electrical generating capacity had been restored and daily blackouts were a fact of life. With the destruction of Iraq's power generating capacity, Iraq was no longer able to run its water-pumping stations and sewage treatment plants, depriving the Iraqi people of a hygienic source of water. In preparation for the October 2003 Madrid Donor Conference, the joint United Nations/World Bank team conducted an assessment of funding needs for reconstruction in Iraq during the period 2004–2007. The resulting report identified 14 sectors and associated funding needs of US$36 billion. The Coalition Provisional Authority estimated an additional US$20 billion in need including US$5 billion for security and police and US$8 billion for oil industry infrastructure [13].

Furthermore, a comprehension housing problems occurred and in its totality has resulted in a large proliferation of slums and unauthorized public building in all Iraqi cities and specially the capital Baghdad. Also, there were and till now many of unemployed educated, the destitute, senior citizens and working women, which when combined, comprise almost 1/4 of Baghdad's urban population [14]. However, the government hadn't spent the large budget gained from potential resources on projects for the benefit of these groups. The demands are growing at a faster rate than the delivery system. Such disorientation puts severe environmental constraints upon cities dwellers. The government's efforts to solve this problem were not adequate by increasing investments in urban areas, leading to inadvertent migration resulting in these high densities, unliveable cities. This problem seems till now without apparent feasible solution in sight, rolling along like the veritable snowball, ever increasing in size [15].

In developing countries it is often not necessary to implement completely new building methods and materials in order to provide a safe life at a suitable human level. Local building practices in Iraq have not been assessed yet and weaknesses and strengths identified considering the local type and recurrence of natural hazards. Simple and expensive buildings were constructed during the past few years combined with poor quality construction methods. The materials used in these constructions were produced in the same traditional poor technologies without required care that must be taken to ensure that an adequate skills base exists for their use, or that training is provided, in order to avoid increased poor construction. The design of critical facilities and infrastructure that are essential for relief and recovery purposes in the event of a disaster are not given special consideration. The adoption of hazard-proof criteria set out in codes of practice for normal structures are not adequate in these buildings and the non-operation of these facilities was not socially acceptable. New developments should be implemented in construction performance based design of critical facilities to allow for the lower level of socially acceptable risk [16].

4. Justifications and Objectives

Developing countries wish to see all construction companies integrate sustainability into their development approaches to create more sustainable building projects. This will have important implications for construction companies involved in social rebuilding and will require placing sustainability instead of the traditional construction practice. Iraq looks to achieve economic development to secure suitable standards of living for people. It is well known that the consideration of sustainability early in a project's evaluation processes can result in less of an increase in capital costs than those made at a later stage. Therefore, the involved construction companies should be aware of the importance of early stage of potential project design decisions.

The developing cities in Iraq like Baghdad is having a rapid annual growth in construction sector which contributes about 6 million people. The existing multi story buildings and many public buildings are destroyed during the war 2003 and the civil war 2006–2008. Therefore, the reconstruction campaign becomes essential to construct new buildings by the real estate contractors and international construction companies which can create a significant stress on water, energy and waste management.

This paper is an attempt to address the sustainable construction approach and how to be accepted in the developing countries based on existing socio-economic and environmental condition. Construction sector in Iraq has considered its projects to have long life cycle value especially during infrastructure rebuild. After the war Iraqi engineers realized that they should work on processes, services to the users of facilities. Quite recently infrastructure and housing are stated to be the main users of resources and the main producers of environmental burdens. The quality of the built environment is also claimed to contribute to the quality of life. Therefore, Iraqi construction sector should without delay develop its construction processes towards sustainable direction to remedy the built environment.

The main research objectives are:

- Describing a comprehensive sustainability concept understanding, practicing, and implementing.
- Identifying current approaches to building construction practices.
- Identifying the sustainability ideas, evaluation and continuous improvement in Iraqi companies.
- Exploring the reality of sustainability impact on project construction in Iraq as a developing country.

5. Field Survey and Methodology

The field survey was conducted by participation of many Iraqi construction companies. These companies have business contracts and actual involvement in rebuilding projects in Iraq. A questionnaire was used to cover the qualitative implementation of sustainability principles, various concepts, evaluation and continuous improvement of Iraqi infrastructure. The main focus was to identify the sustainability impact on the construction management in the Iraqi companies.

The questionnaire was prepared according to the main sustainability principles indicated in the literature review. The survey has been carried out in Iraq to study the reality of construction management relative to sustainability impact and to find how the Iraqi engineers respond to sustainability concepts and principles, and was conducted for a statistical sample of 20 (public and private) construction companies in Iraq.

The research sample included 50 personnel who have significant role in construction field such as project managers, company managers, contractors, professional engineers, social, and economical professionals. These participants have an active experience in construction field between 10 to 30 years. The majority of them have been involved with more than 20 projects with project cost within the range of 1 to more than 10 million dollars. The respondent profiles for the field survey for the construction companies are 70% public sector and 30% private sector. The questionnaire lists distributed were 70 and the collected was 20 not complete thus ignored and the 50 complete respondents profile is demonstrated in Table 1.

Table 1 The participants profile.

No.	Participants	Numbers	Percentages
1	Companies Managers	5	10%
2	Project Managers	6	12%
3	General Contractors	6	12%
4	Social Professionals	4	8%
5	Economy Professionals	4	8%
6	Architects	7	14%
7	Civil Engineers	7	14%
8	Mechanical Engineers	4	8%
9	Electrical Engineers	3	6%
10	Environment Engineers	4	8%
Totals		50	100%

6. Results and Discussion

The literature review shows that the sustainability concept is not well defined, recognized, and implemented in the construction industry in developing countries. To show how far sustainability concept has penetrated the construction industry, a field survey has been conducted among construction companies in Iraq which focuses on the research sample identifying this subject and whether they have incorporate knowledge within their current projects.

The data and information collected from participating companies were analyzed to recognize the reality of sustainability concept understanding, practices, future perspective for implementation, and the impact of sustainability on various aspects in Iraqi rebuilding projects.

The data gathered was analyzed qualitatively and quantitatively. The statistical analysis was used to calculate straightforward totals, percentages and averages. Qualitative technique was applied to make sense of meanings. Interviews were used to connect statements, opinion and comments to provide a complete picture. The results are discussed as follows:

7. Sustainability Understanding and Implementation

The level of knowledge among research sample is demonstrated in Fig. 3 with regards to sustainability concept, the respondents were asked to rate their knowledge on this subject matter and what they perceived, based on their experience. As shown in Fig. 3 only 18% of the respondents have a moderate sustainability understanding relies on written materials or very limited internet websites to improve their knowledge about sustainable construction. Other sources of knowledge are through education, seminars and conferences. Meanwhile the majority of respondents have 42% of very poor knowledge about sustainability. The learning level indicates that most of the companies should promote sustainability concept within their organizations.

Aligned with the level of knowledge revealed by the respondents, the level of implementation is also at very poor level 50% and 35% considered it low as shown in Fig. 4, and none of the respondents considered that the implementation of sustainable practices is excellent.

The respondents were requested to give their opinion on the prospect of sustainable construction application in Iraq in the next 5 years depending on current construction projects applications. Fig. 5 shows clearly that 45% of the respondents believed that in the next five years, there will not be much change and the level is still at low level. About 15% of respondents believed that it will get a moderate level, while 10% of the respondents considered it would be good, while the whole respondents believe that no way to get excellent level.

8. Traditional Construction Design Approach

The sustainable construction concepts are not clearly recognized in Iraqi construction field as shown in Fig. 3. The traditional design approach is still the main practice in the construction companies in Iraq which focuses on cost, quality and time. Fig. 6 shows the importance of each factor. The majority of the survey respondents 60% considered that cost is the major factor to be considered during design stage of construction projects. Regarding to time factor there was only 25% of the respondents who indicate that project scheduling and maintaining the total project duration is very important in project construction planning. The respondents didn't focus on quality as an important factor to achieve the projects successfully where only 15% of them consider it important to conform to standards and specifications stated in the project design.

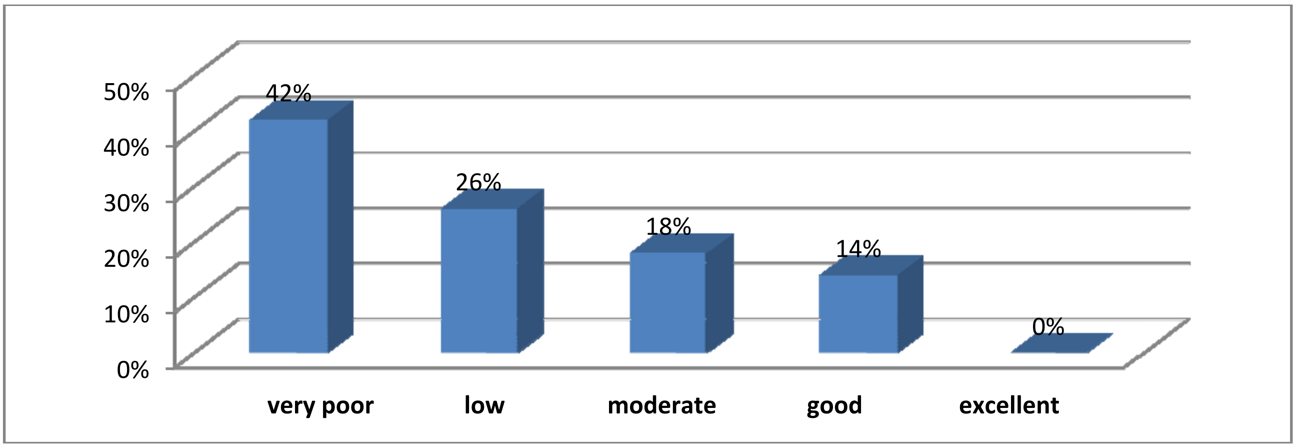


Fig. 3 Levels of understanding sustainability concept.

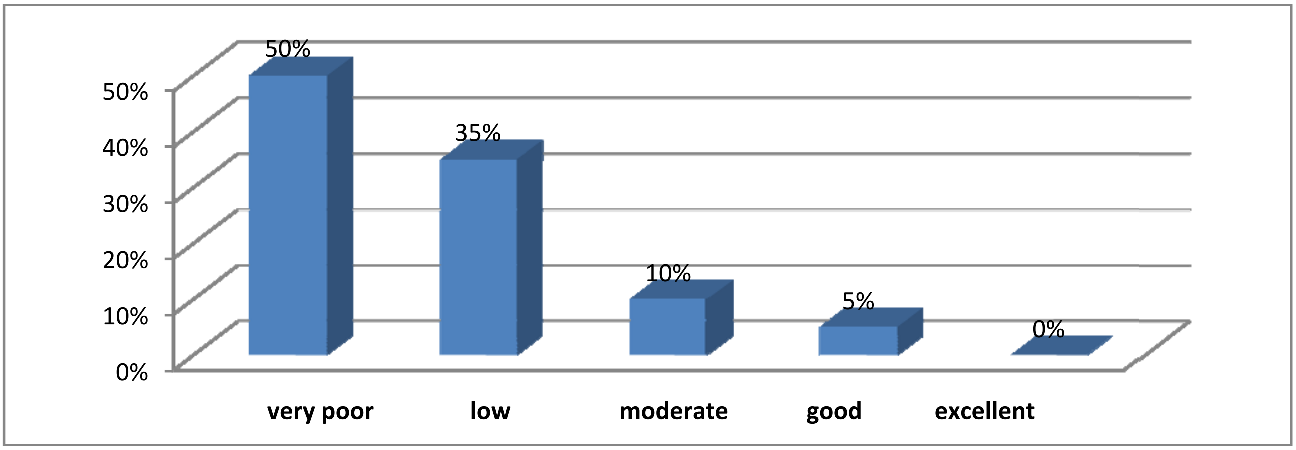


Fig. 4 Implementation Levels of Sustainability Practices in Iraq.

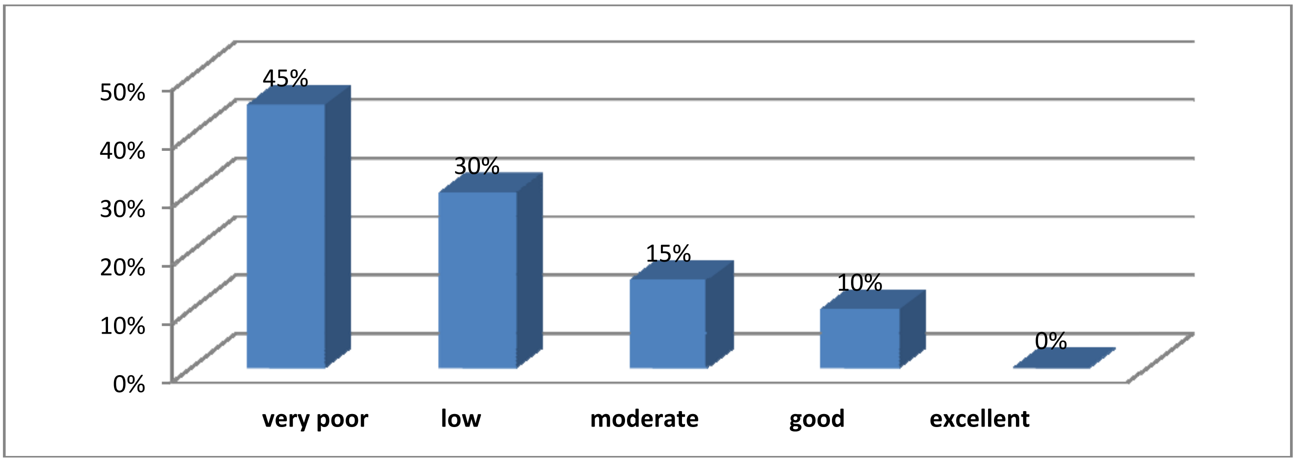
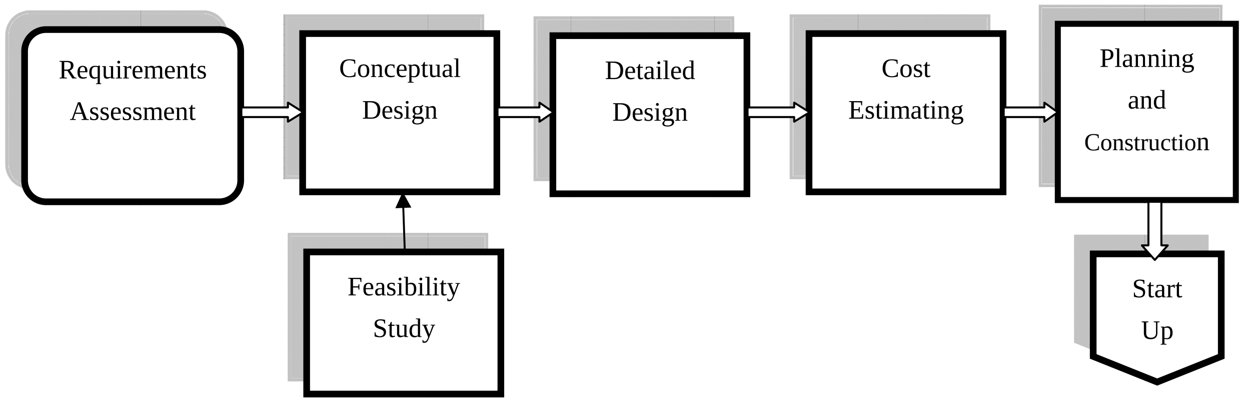


Fig. 5 Prospect of Sustainability Practices in 5 Years in Iraq.



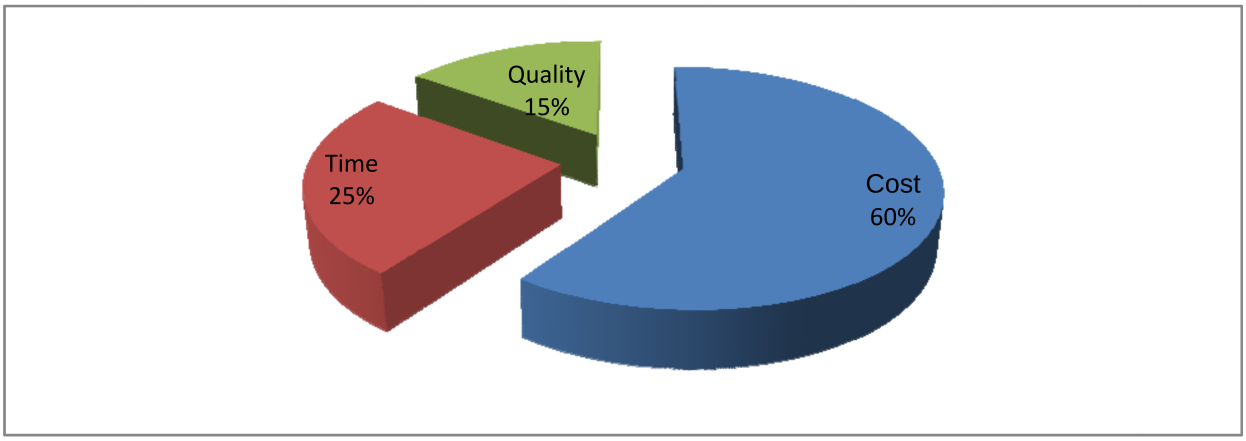


Fig. 6 Traditional design approach.

9. Sustainable Construction Design Approach

The research sample was asked simultaneously about the impact of the sustainability approach on the construction management practices to verify their responds towards this new issue. As shown clearly in Fig. 7, the majority of the respondents 55% consider that the most important factor is the economy, while 35% of them considered the environment requirements in new sustainable construction design are important, and only 10% of the respondents takes the social factor of the sustainable design approach into consideration which indicates clearly how the disaster conditions passed in Iraq reflect a great ignorance for human life related to providing suitable residential homes, These results show that the traditional construction approach is still applicable in the Iraqi construction companies while the sustainability impact has not essential basis to be practiced or implemented in construction design. These companies could not realize that the sustainable design is an integrated design where each component is considered as a critical part of the whole successful sustainable design compared with traditional design. Early decisions have the greatest impact on energy efficiency, passive solar design, day lighting, and natural cooling. Furthermore, the sustainable buildings do not have to cost more, nor are they more complicated than traditional construction.

Fig. 8 shows a comparison between the traditional and sustainability concepts simultaneously where the blue line refers to the dominant traditional design approach which is upper than the sustainability importance red line. Fig. 9 shows the sustainability design approach where sustainability requirements could be implemented during the early stage of the design process and evaluated at each design phase throughout the value engineering.

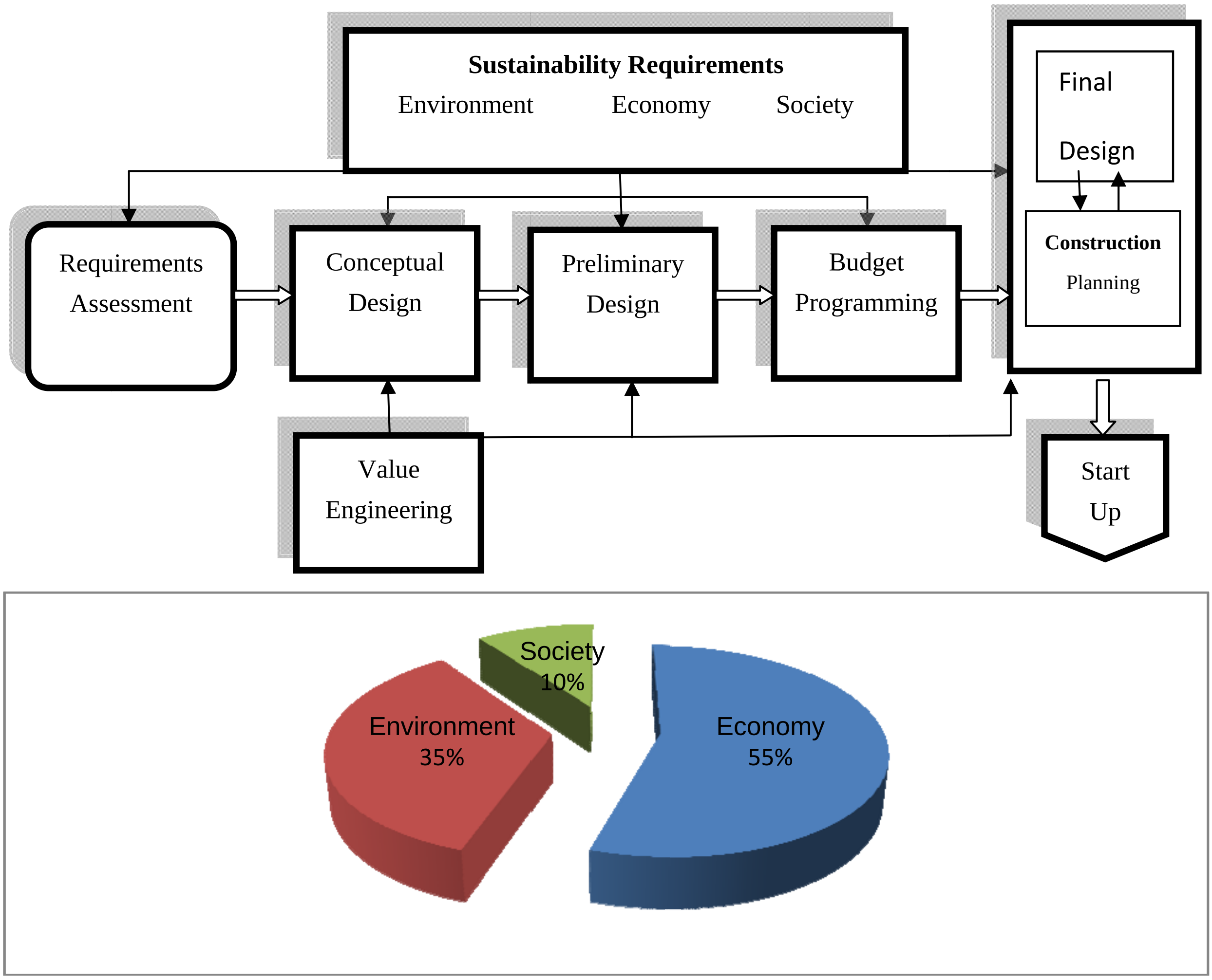


Fig. 7 Sustainable design approach.

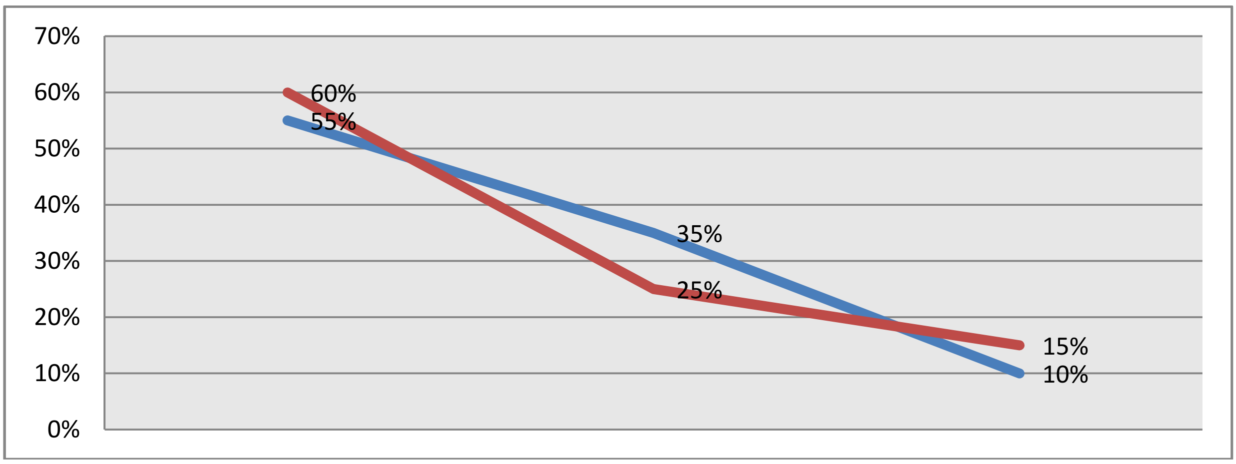


Fig. 8 Comparison between the traditional and sustainability concepts importance.

10. Sustainability Principles

The concept of sustainable construction that governs environmental protection, social well-being and economic prosperity has been investigated to illustrate how the construction companies in Iraq respond to these areas of concern and to show the sustainability impact on current construction player, where the respondents indicate clearly that these companies could be acting successfully to implement sustainable construction by creating suitable built environments, and restoring damaged and polluted environments.

They realize that in order to achieve sustainability, the construction management policy in Iraq should change the processes of creating the built environments. This could be achieved by changing the linear processes to cyclic processes within the construction industry, and it is shown in Fig. 9 where the respondents revealed that the of various environment aspects have a significant importance as following: (location and land utilization 15%,material selection 20% energy conservation 16%, water quality 18%, waste minimization 8%, pollution control 13%, and biodiversity and ecology 10%) for changing the way in which all the construction activities are undertaken.

Regarding to the social factors mentioned in Fig. 2, the respondents show the construction companies that involved in real projects to rebuild the infrastructure in Iraq should take into consideration the important sustainability implications of social requirements which are shown in Fig. 10, where the research sample realized the importance of health and welfare by 20%, safety 16%, user comfort and satisfaction 18%, accessibility 14%, aesthetics 12%, nuisance to neighbors 8%, and social involvement 12%.

As shown previously in Fig. 6 that the majority of the respondents considered that cost and the economy are the major important factors whether in traditional or in sustainable building construction approaches. The results shown in Fig. 11 indicated that the respondents found the importance of the economical aspects as

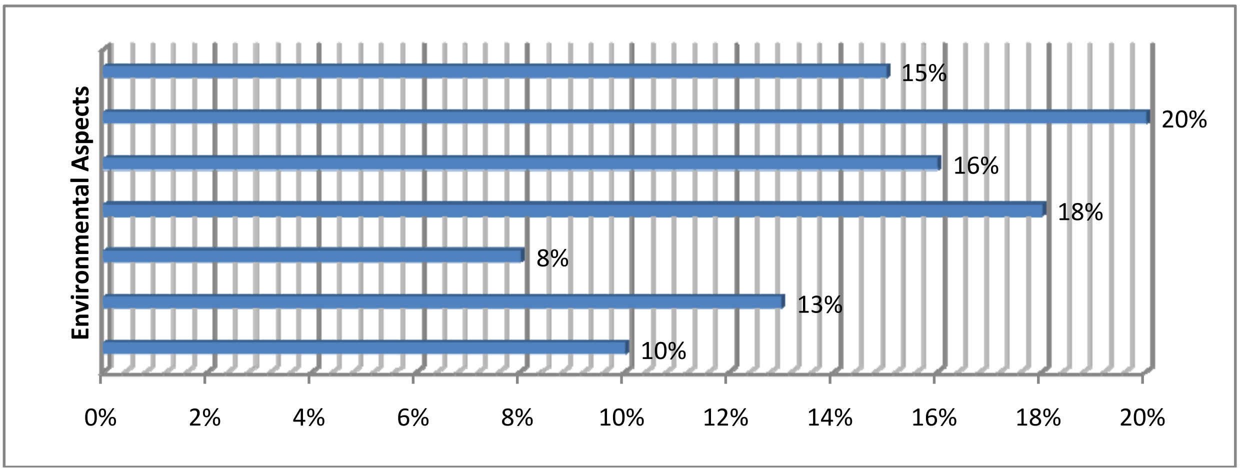


Fig. 9 The importance of the environmental aspects.

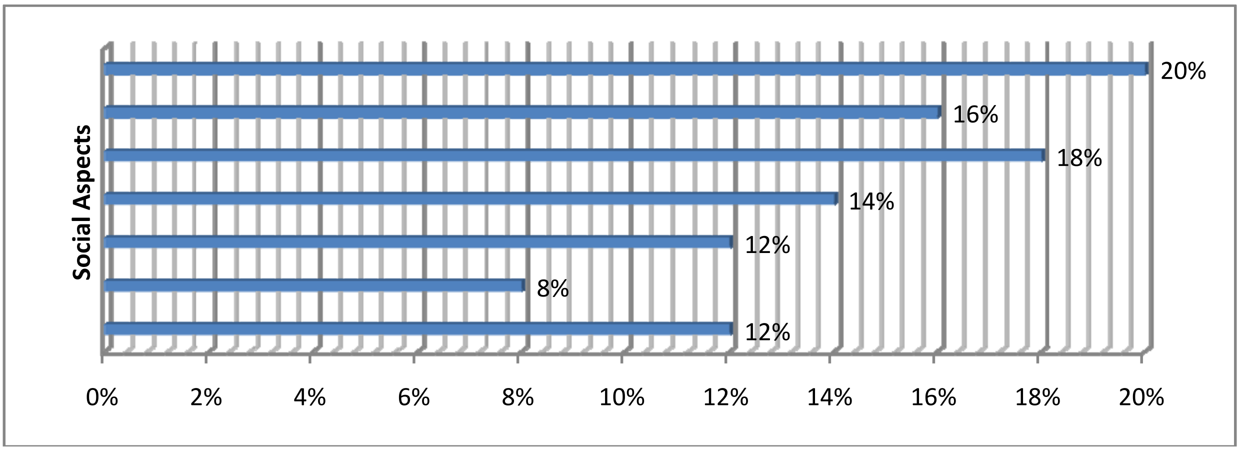


Fig. 10 The importance of the social aspects.

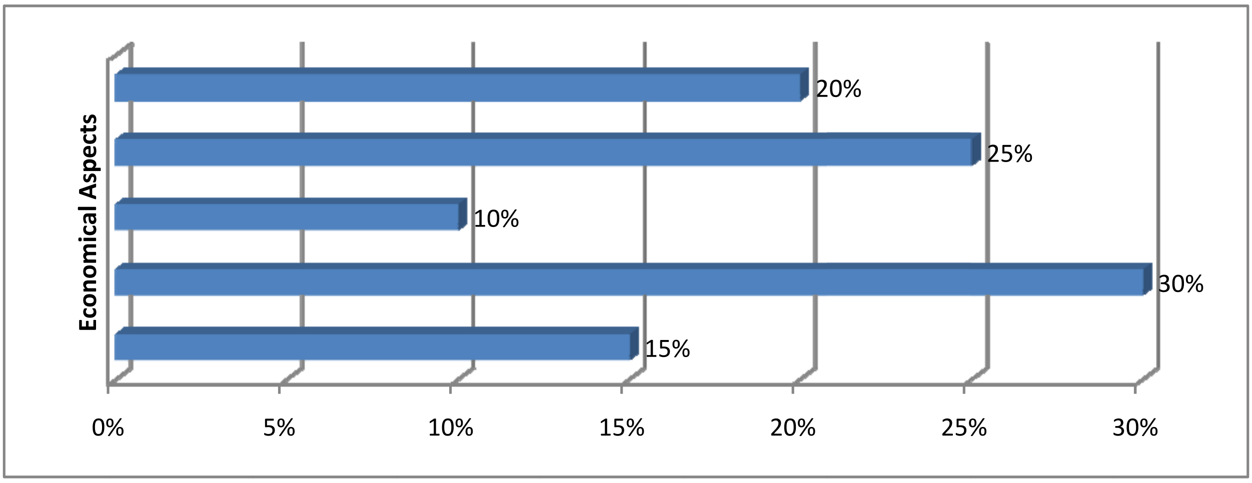


Fig. 12 The importance of the economical aspects.

following (whole life cost 20%, image and business enhancement 25%, legislation compliance 10%, cost efficiency 30%, and risk assessment 15%).

11. Conclusions

The main conclusions deduced from the research can be illustrated as followings:

(1) There are many respondents stress the need for enforcement through law and legislation to increase educational opportunities to have more knowledge about sustainability concepts and implementation in construction field.

(2) The respondents highlighted the necessity of professionally qualified players in the construction industry in Iraq to improve the sustainability practices and implementation properly.

(3) The results showed that the respondents have poor knowledge about sustainability, where the learning level of sustainability concepts in the construction companies should be promoted within their organizations. This requires cooperation with construction experts for the development of appropriate educational and training.

(4) The Iraqi construction companies could not realize that the integrity of the successful sustainable design compared with traditional design, and the sustainable buildings which do not have to cost more, nor are they more complicated than traditional construction.

(5) Iraq is facing a disaster conditions and serious need to accelerate sustainability implementation in reconstruction of the infrastructure in general and to raise the living standards of the populations, meanwhile, reducing energy costs, pollution and to promote the use of renewable materials and energies that should be the priority in any action taken to protect the environment.

(6) Many respondents believed that sustainability can be implemented successfully in the Iraqi construction projects if the management policies oriented by governmental financial support, where they still suppose that sustainable practices increase project cost.

(7) The respondents show a high consideration to the importance of various sustainability principles which can improve the whole infrastructure reconstruction projects in Iraq.

(8) There is a need for a better understanding of the management performance after disaster conditions where the infrastructure and traditional building materials and technologies have to be promoted research into design of structures to reduce the effects of expected hazards.

(9) Post-disaster reconstruction projects present a real necessity for hazard-proof measures in

construction and land use planning which sustainability approach provided. Delegation of national, international companies and humanitarian agencies should coordinate in such conditions.

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Modeling Bridge Condition Levels in the United States

Denver Tolliver and Pan Lu
Upper Great Plains Transportation Institute, North Dakota State University, Fargo, ND58105, USA

Abstract: The objectives of this paper are to (1) quantify the effects of age and other key factors on bridge deterioration rates, and (2) provide bridge managers with strategic forecasting tools. A model for forecasting substructure conditionisestimated from the National Bridge Inventory that includes the effects of bridge material, design load, structural type, operating rating, average daily traffic, water, and the state where the bridge is located. Bridge age is the quantitative independent variable. The relationship between age and substructure condition is a fourth-order polynomial. Some of the key findings are: (1) a bridge substructure is expected to lose from 0.52 to 0.11 rating points per decade as it ages from 10 to 70 years; (2) levels of deterioration increase significantly as the material changes from concrete, to steel, to timber; (3) slab bridges have lower levels of deterioration than other structures; (4) bridges that span water have lower condition ratings; (5) bridges with higher operating ratingshave higher condition ratings; and (6) substructure condition ratings vary significantly among states.

Key words: Highway bridges, bridge condition levels, bridge deterioration rates, statistical forecasting models.

1. Introduction

Nearly 600,000 bridges located on public roads in the United States are greater than 6.1 meters or 20 feet in length [1]. As stipulatedin the National Bridge Inspection Standards, bridges of these lengths are inspected at least once every two years. During these inspections, the conditions of the three major bridge components (deck, superstructure, and substructure) are rated using a standard scale developed by Federal Highway Administration, which includes eight interim levels between excellent and failure (Table 1). A composite score is assigned by evaluating the severity of the deterioration of individual bridge elements and assessing the extent to which the deterioration or disrepair is widespread throughout the entire component. A rating of 4 or less indicates poor condition or worse and typically results in a bridge being classified as structurally deficient.

Bridge condition assessments and other vital statistics are compiled in the National Bridge Inventory (NBI). According to the NBI, approximately 14% of the highway bridges in the United States longer than 6.1 meters are classified as structurally deficient (Fig. 1). A bridge labeled structurally deficient is not necessarily unsafe or likely to collapse. However, the bridge will incur additional expenses for increased inspection, spot maintenance, and repairs in order to remain in service. Moreover, the maximum gross vehicle weight may be restricted to less than the legal limit. An additional 15% of highway bridges are classified as functionally obsolete, due to substandard lane or roadway widths and other geometric shortcomings. Because of growingdeterioration and obsolescence, the American Society of Civil Engineers [2] has given America's bridges a grade of D on scale from A to E.

According to the NBI, more than one billion vehicles utilize functionally obsolete or structurally deficient bridges in the United States each day. However, this utilization rate does not consider traffic that is diverted from or routed around substandard bridges and the additional distances and travel times required. The average distance to bypass functionally obsolete or structurally deficient bridges is 20 kilometers, suggesting that posted, deteriorated, or substandard bridges may be impeding commerce and mobility.

Corresponding author: Pan Lu, PhD, research fields: GIS applications in transportation; transportation infrastructural management system; freight transportation; environmental analysis; multi-mode transportation. E-mail: pan.lu@ndsu.edu.

Table 1 Condition ratings used in the national bridge inventory.

Code	Meaning	Description
9	Excellent	
8	Very Good	No problems noted.
7	Good	Some minor problems.
6	Satisfactory	Structural elements show some minor deterioration.
5	Fair	Primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	Poor	Advanced section loss, deterioration, spalling or scour.
3	Serious	Loss of section, deterioration, spalling or scour has seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	Critical	Advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	Imminent Failure	Major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic, but with corrective action, may put back in light service.
0	Failed	Out of service -- beyond corrective action.

United States Department of Transportation: Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, Washington, D.C., 1995, p. 38.

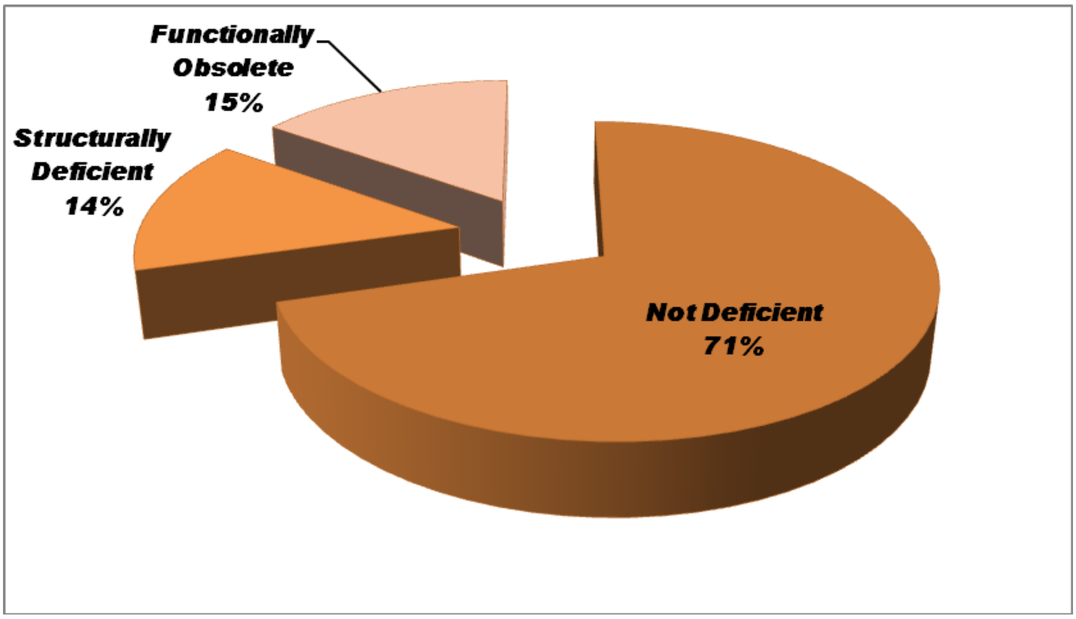

Fig. 1 Status of highway bridges in the United States.
Computed from the 2009 National Bridge Inventory, including bridges > 6.1 m in length, with culverts excluded.

The objectives of this paper are two folds: (1) to quantify the effects of key factors on bridge deterioration rates and (2) to provide bridge managers with forecasting tools to help them project condition ratings as a function of age, bridge type, material, and geographic and jurisdictional location. In the United States, the Federal Highway Administration has developed the National Bridge Investment Analysis System (NBIAS) to analyze and forecast bridge conditions. The NBIAS analyzes deficiencies at the level of individual bridge elements (such as beams, trusses, girders, cables, etc.) using the National Bridge Inventory. A probabilistic method of modelling bridge deterioration is used in which transition probabilities are used to project the likelihood that a bridge element will deteriorate from its current condition state to a lower condition level during a future interval. The NBIAS assumes that the probability of a bridge element deteriorating from its current condition to the next (lower) level is independent of age.

Muchof the research in the area of bridge managementhas focused on predictions derived from Markov Chains using transition probabilities. In these models, the probability that a bridge (or bridge element) will be in a certain condition at time t_1 is a function of its condition at time t_0.While useful, Markov Chainsare based on simple, often unrealistic assumptions. (1) The future condition of a bridge is dependent only on its current condition: i.e., the history of bridge deterioration in previous periods is not taken into account. (2) A bridge stays in acondition state for a predefined time. At the end of each time period the bridge either moves to a new state or stays in the same state for another predefined period. (3) The transition probabilities are constant over time.

Less emphasis has been given tolong-term predictive models inwhich future bridge conditions are forecasted from a set of explanatory variables. Nevertheless, in the literature it is possible to find information that age is a key determinant of deterioration [3–5] and otheressential bridge features contribute significantly to bridge deterioration [5–7].

Roughly half of the highway bridges in the United States were constructed prior to 1970 (Fig. 2), so age is a key consideration in bridge analysis. As noted by the United States Department of Transportation [1] if a bridge's age (independent of current condition) has an effect on its deterioration rate "this could create a situation in which bridge investment needs would be clustered in certain time frames rather than distributed more evenly over time. To the extent that such spikes can be anticipated, such information would be very useful in designing system-wide bridge management strategies."Before describing amodelthat canbe used forstrategic planning, some essentialbridge features are defined: (1) design load, (2) material type, (3) structural type, and (4) operating rating.

2. Bridge Characteristics

2.1 Structural and Material Types

The National Bridge Inventory classifies bridges into 23 structural categories. As shown in Fig. 3, the most common structural types are stringer (53%), slab (17%), tee-beam (10%), and box-beam/girder (8%). The remaining 19 categories (which include arch, truss, suspension, frame, and floor-beam/girder structures) comprise 12% of all bridges. Fig. 4 shows that concrete

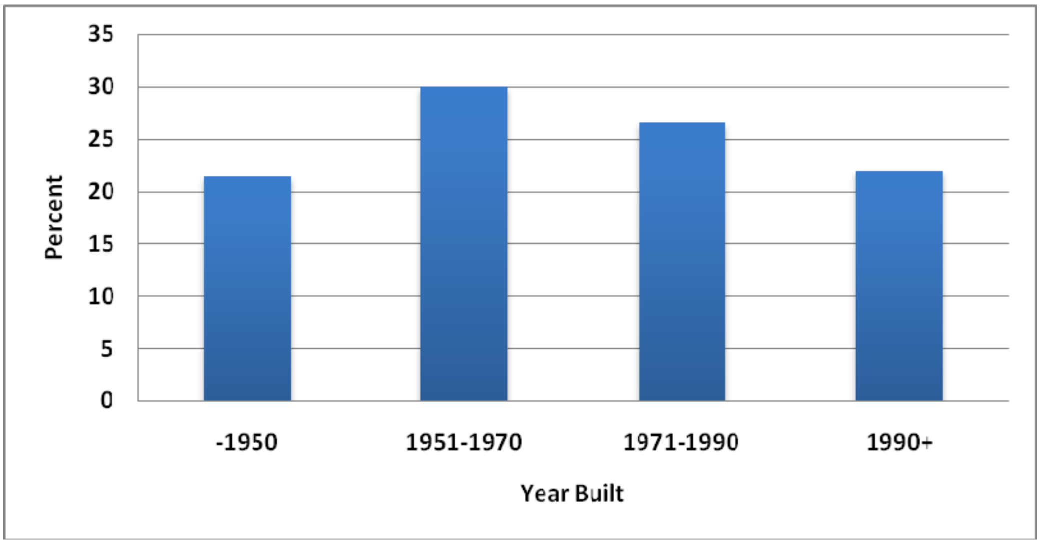

Fig. 2 Year of construction of highway bridges in the United States.
Computed from the 2009 National Bridge Inventory, including bridges > 6.1 m in length, while excluding culverts.

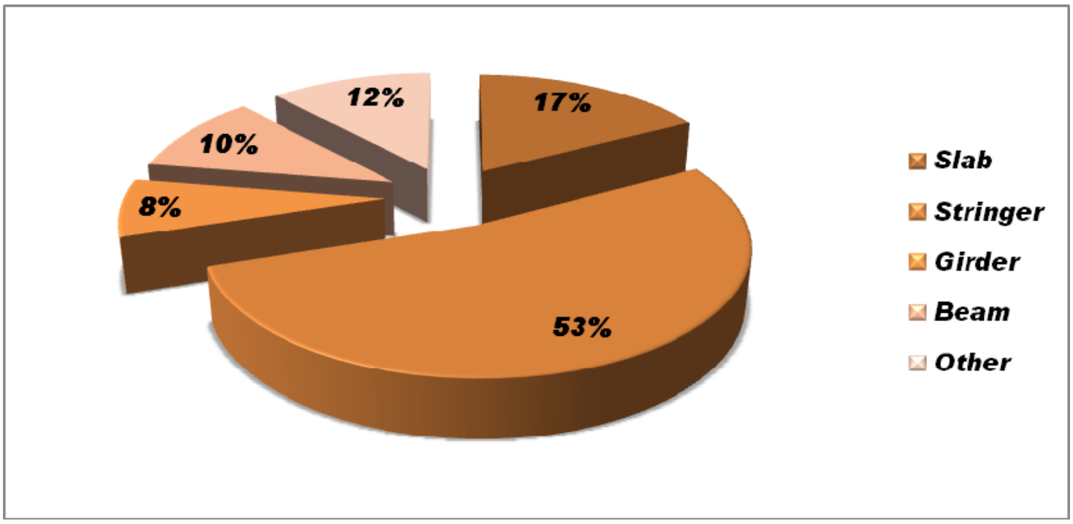

Fig. 3 Classification of highway bridges in the United States by structural type.
Computed from the 2009 National Bridge Inventory, including bridges > 6.1 m in length, while excluding culverts.

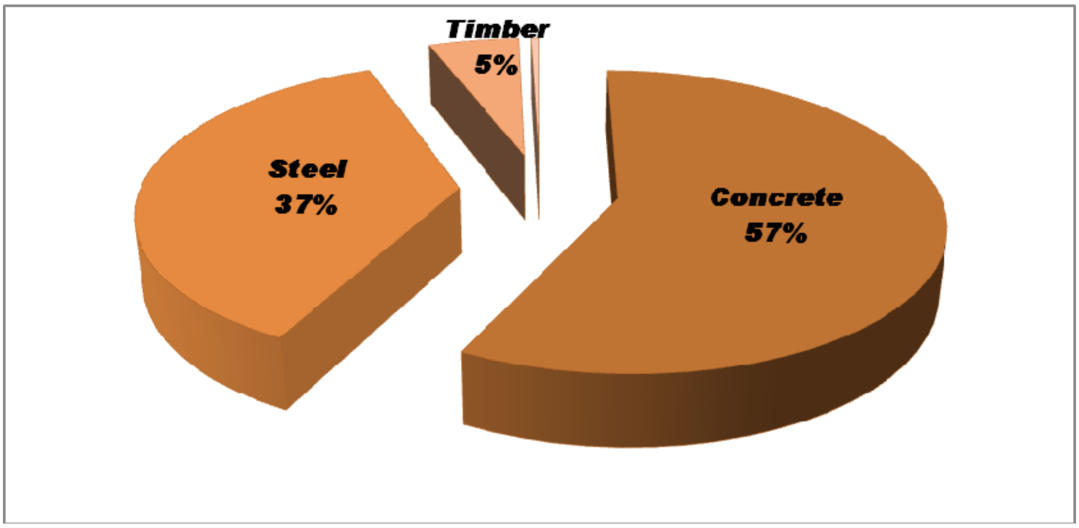

Fig. 4 Highway bridges in the United States by dominant material.
Computed from the 2009 National Bridge Inventory, including bridges > 6.1 m in length, while excluding culverts.

is the dominant construction material in more than 57% of the highway bridges in the United States, while steel is the primary material in nearly 37% of bridges.

2.2 Design Load

In the United States, the American Association of State Highway and Transportation Officials (AASHTO) has defined prototypical vehicles for analyzing bridge loads. The alphanumeric codes associated with these vehicles start with "H" or "HS." A prefix of H denotes a single-unit truck, whereas HS denotes a tractor pulling a semitrailer. For H bridges, the numeric suffix represents the gross weight in tons of a single-unit truck. For example, H-10 denotes a truck with a gross weight of 10 tons (9.07 metric tons), while H-20 signifies a 20-ton truck. In comparison, the numeric suffix of HS vehicles represents the assumed weight on the first two axle sets of the truck: e.g., the weight distribution to the tractor's steering and driving axles. For example, HS-20 signifies a truck with a total of 20 tons (18.14 metric tons) on the tractor's axles and additional weight on the semitrailer's axle. As shown in Table 2, 49% of the bridges in the United States are HS-20 or HS-20^{+} bridges.

2.3 Operating Rating

The operating rating is the maximum permissible live load that can be placed on a bridge without a special permit. Although the maximum gross vehicle weight on the interstate highway system of the United States is 40 tons, bridge operating ratings may be higher or lower than 40 tons. In fact, 85% of the bridges in the United States (excluding culverts) have operating ratings of less than 40 tons. Fifty percent of bridges have operating ratings of less than 24.5 tons.

The operating rating provides unique information not necessarily reflected in the design classification. As illustrated in Table 3, H-10, H-15, and H-20 bridges are distributed differently among rating classes. An H-10 bridge with an operating rating > 40 tons is superior to an H-10 bridge with an operating rating ≤ 20 tons. In this paper, bridge material, design load, structural type, and operating rating are used to collectively describe the quality dimensions of a bridge. However, due to the categorical diversity within the "other structures" group (which includes 19 different types), and the limited number of observations in the "other material" category (which includes only 1% of the observations), the analysis focuses on the primary bridge materials of concrete, timber, and steel and the four main structural types of stringer, slab, tee-beam, and box girder.

Table 2 Percentages of highway bridges in the united states designed for specific vehicle loads.

Design Load	Number of Bridges	Percent of Bridges
H-10	11,275	2.42%
H-15	66,430	14.24%
H-20	35,701	7.65%
HS-15	10,127	2.17%
HS-20	173,581	37.20%
HS-20 Plus	54,131	11.60%
HS-25	19,728	4.23%
Other	95,628	20.49%

Computed from the 2009 National Bridge Inventory, including bridges > 6.1 m in length, while excluding culverts.

Table 3 Distribution of operating rating by design load category.

Operating Rating (Tons)	Percent of Bridges by Design Load		
	H-10	H-15	H-20
≤ 20	40.2%	6.7%	2.7%
> 20 and ≤ 30	19.9%	14.3%	4.9%
> 30 and ≤ 40	28.3%	21.8%	17.6%
> 40	11.5%	57.2%	74.9%

Computed from the 2009 National Bridge Inventory, including bridges > 6.1 m in length, while excluding culverts.

3. National Bridge Model

A statistical forecasting model of bridge condition rating is presented in this section of the paper. First, the model form, main effects, and variables are discussed, followed by a summary of the results and parameter estimates. After the estimates are analyzed, methods of forecasting with the model are introduced.

3.1 Model Form and Main Effects

In a statistical analysis, separate models can be estimated for each unique category of a dependent variable. However, in doing so, an implicit assumption is made. The assumption is that there are no interactions among categories. While categories of bridges do not interact physically, they are often managed by the same agency; thus, all bridges within a given jurisdiction are subject to a global budget cap.

The approach taken in this study anticipates that the financial resources and attention given to various categories of bridges within a state may not be independent. Consequently, a multivariate model is formulated includingeight effects: bridge type, design load, structural type, operating rating, average daily traffic (ADT group), whether the bridge crosses water, whether the bridge has been reconstructed, and the statein which the bridge is located. The values or levels associated with these effects are summarized in Table 4.

The effects are defined as indicator or indicator variables. To avoid singularity, only n−1 indicator variables are used to represent a given effect. Each category has its own unique intercept. However, the slope (or rate of change in substructure rating with age) is the same after controlling for all effects.

Table 4 Class level information: national bridge substructure model.

Class Variable	Levels	Values
Reconstructed	2	0, 1
Bridge Material	3	Concrete, Steel, Timber
Design Load	8	H-10, H-15, H-20, HS-15, HS-20, HS-20+, HS-25, Other
Structural Type	4	Stringer, Slab, Beam, Girder
Operating Rating	4	20 tons, 20.1–30 tons, 30.1–40 tons, > 40 tons
Water Span	2	0, 1
ADT	5	<= 100; 101-1000;1001-5000; 5001-19,000; > 19000
State	50	AK AL AR AZ CA CO CT DC DE FL GA HI IA ID IL IN KS KY LA MA MD ME MI MN MO MS MT NC ND NE NH NJ NM NV NY OH OK OR PA RI SC SD TX UT VA VT WA WI WV WY

3.2 Dependent Variable

Kim and Yoon [5] studied bridge decks and superstructures and found that age is the most significant contributor to the structural deficiency of decks and bridge superstructures in cold regions, followed by the structural characteristics of the bridge and traffic volume. In a complementary way, this paper focuses on bridge substructures — which include elements such as piers, abutments, footings, and foundations that transfer loads from the deck and superstructure to the ground.

Substructure condition (dependent variable of the model) is treated as an integer-scaled variable using the scale shown in Table 1. A change of one unit anywhere on the scale has the same statistical effect.

The interpretation of bridge condition as an integer-scaled variable is acceptable because the purpose of this study is to forecast when condition ratings will change, neglecting the seriousness of the changes or the need for remedial actions. Nevertheless, a corollary issue exists: the condition ratings may be scored differently by different bridge inspectors. To a certain extent the differences may be reflected in the state indicator variables, which describe the general location and administrative jurisdiction of the bridge, because these differences change geographically among states or are attributable to inspectors drawn from different states.

3.3 Functional Relationship between Condition and Age

The age of each bridge is computed as 2009 minus the year of original construction. Theoretically, the rate of bridge deteriorationcan be described by polynomial function instead of linear function. This hypothesis is based on two suppositions. (1) When the bridge is deteriorated to fair condition, maintenance and repairs are implemented to keep itin acceptable condition. These improvements may slow the rate of deteriorationover time. (2) Once a bridge is in serious condition (described in Table 1) it may continue in light service, limiting the traffic loadsand making spot repairs.

A scatter plot of mean substructure ratings against age exhibits a higher-order polynomial formas shown in Fig. 5. Examination of the scatter plot in Fig. 5 shows: (1) bridge rating was highly dependent on age; (2) bridge rating exhibits a clearly higher-order polynomial relationship with age; and (3) observations for bridges of approximately the same age are very close or clustered with each other until around age 120. After age 120, the observations begin to spread out. The main reason for bridges that are over 120 year age mark a wider condition range is the result of the bridges being built before design rules of standardization.

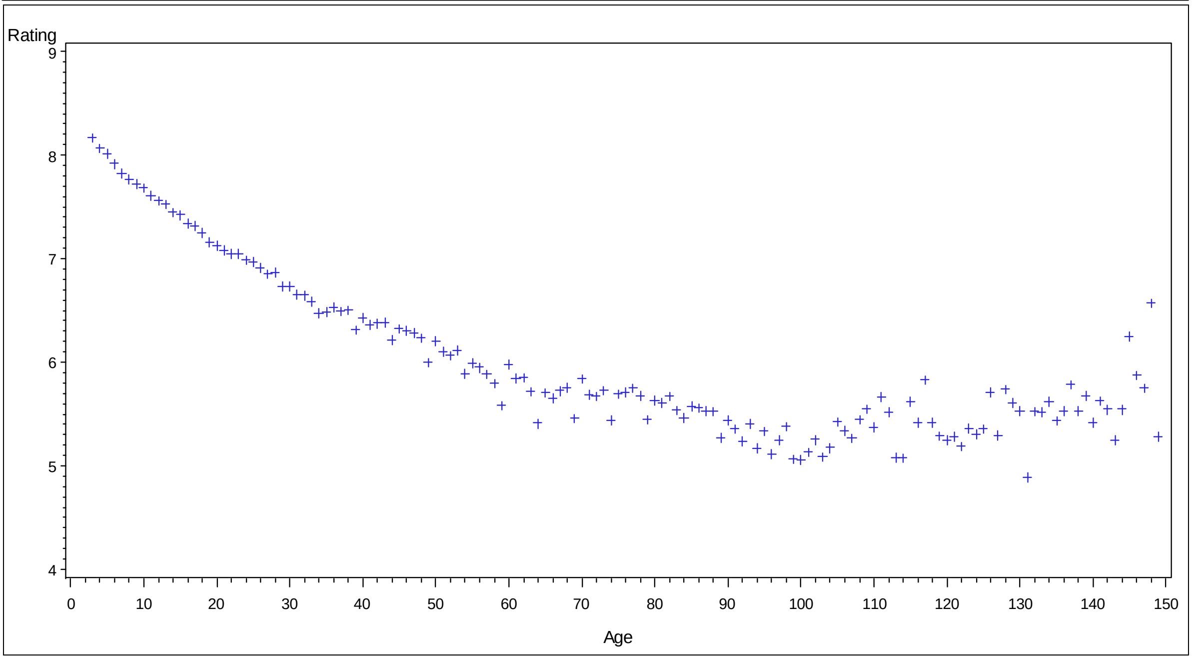

Fig. 5 Scatter plot of mean bridge substructure condition ratings and age.

While these bridges are important, the analysis is restricted to bridges ≤ 120 years of age. Reasons for this are: (1) bridges built under bridge design standardizations should be researched separately from bridges not built to design standards, (2) bridge design standardization's effect on bridge deterioration is out the scope of the analysis, and (3) the relative high variation of bridge ratings for bridges that are more than 120 years old will jeopardize the quality of the forecasting model.

3.4 Model Properties

The overall results of the substructure regression model are summarized in Table 5. "F-Value" and "Prob(F)" statistics test the overall significance of the regression model. Specifically, they test the null hypothesis that "all of the regression coefficients are equal to zero." If the model explains much of the variation in condition rating, the F-Value will be large and Prob(F) will be small.

Table 5 Regression summary for national bridge substructure model.

Number of Observations Used	409,993
Degrees of Freedom (DF)	409,918
F-Value	4,899.6
F-Test for Model Fit (Prob(F). > F)	<.0001
R-Square	0.4694
Adjusted R-Square	0.4693
Coefficient of Variation	14.29

The F-value equals Mean Square Model divided by Mean Square Error (F = MSM/MSE). Where MSM equals Sum of Square for Model divided by Degree of Freedom for Model (MSM = SSM/DFM) and MSE equals Sum of Square for Error divided by Degree of Freedom for Error (MSE = SSE/DFE). The F-Value ranges from zero to an arbitrarily large number.

The value of Prob(F) is the probability that the null hypothesis for the full model is true (i.e., all of the regression coefficients are equal to zero). In this case, an F-value is 4,900 and the Prob(F) value is <0.0001, which indicates a less than 1in 10,000 chance that all of the regression parameters are zero. This would imply that at least some of the regression parameters are nonzero and that the regression equation fits the data with validity. The F-value does not indicate which variables are most significant and if all of the effects are statistically meaningful.

3.5 Incremental Sum of Squares Tests for Effects

The bridge model must still be determined if the theoretical effects are statistically significant in the NBI dataset. Each variable effect is evaluated using Type I and Type III sums of squares. Type I sums of squares are called sequential sums of squares. They are computed by sequentially adding variables to a model (one at a time) and computing the reduction in the error sum of squares attributable to a particular explanatory variable. Thus, the Type I sums of squares indicate how much the residual sums of squares are reduced by adding the particular explanatory variable to the model that contains all other variables. The corresponding p-value can test the hypotheses:

H_0: the specific regression coefficient = 0 given that no other independent variables are included in the model.

H_A: the specific regression coefficient ≠ 0 given that no other independent variables are included in the model.

A p-value that is < 0.0001 indicates a less than 1 in 10,000 chance that the specific regression coefficient is zero given no other independent variables are included in the model.

In comparison, Type III sums of squares are called marginal sums of squares. They reflect the incremental contribution of a specific variable when it is added to a model that already includes all other variables. For this reason, Type III effects are often referred to as partial sums of squares. Thus, the Type III sums of squares indicate how much the marginal sums of squares are added when all the other independent variables are already included in the model. The corresponding p-value can test the hypotheses:

H_0: the specific regression coefficient = 0 given that all other independent variables are included in the model.

H_A: the specific regression coefficient ≠ 0 given that all other independent variables are included in the model

A p-value that is < 0.0001 indicates a is less than 1 in 10,000 chance that the specific regression coefficient is zero given that all other independent variables are included in the model.

As shown in Table 6, all the sum of squares tests are highly significant for the all eight main effects with p-values of <.0001, indicating these variables improve the explanatory power of the model.

Table 6 Incremental sum of squares tests for national bridge substructure model.

Source	Type I Sum of Squares			Type III Sum of Squares		
	Mean Square	F-Value	Pr. > F	MeanSquare	F-Value	Pr. > F
Reconstructed	7,395	8,335	<.0001	3,088	3,481	<.0001
Bridge Material	26,387	29,742	<.0001	2,114	2,383	<.0001
Design Load	13,116	14,784	<.0001	727	820	<.0001
Structural Type	804	906	<.0001	29	32	<.0001
Operating Rating	9,020	10,167	<.0001	5,127	5,779	<.0001
Water Crossing	740	834	<.0001	274	308	<.0001
State	861	970	<.0001	640	721	<.0001
ADT	1,140	1,285	<.0001	128	144	<.0001
Age	75,764	85,398	<.0001	6,332	7,137	<.0001
Age^2	15,926	17,951	<.0001	1,177	1,326	<.0001
Age^3	645	727	<.0001	546	615	<.0001
Age^4	401	452	<.0001	401	452	<.0001

3.6 Coefficient of Variation and R-Square

The coefficient of variation (CV) is 14.29 (Table 5). It is computed by dividing the standard error of the regression by the mean value of the dependent variable (CV = σ/μ) and multiplying by 100 to express this ratio as a percentage. The CV is a key indicator of the precision of a model. In this case, the CV is relatively low, which bodes well for prediction.

The R^2 is the ratio of the sum of squares explained by the regression model to the total sum of squares. A higher R^2 is preferred, ceteris paribus. The R^2 value of 0.4694 in Table 5 means that the model explains 47% of the variation in substructure condition rating. Although the effects attributable to bridge type, design load, structural type, operating rating, traffic volume, water, and general location (i.e., state) are captured in the model, many individual bridge effects are not; This could be a reason that the model only explains 47% of the variation in substructure condition rating. The other factors that might contribute to substructure condition rating but are not included in the model can be fixed bridge effects, such as quality controls and conditions during initial construction, the inspectors, the maintenance program used, the amount of maintenance funds available, the frequency of unusual loadings, de-icing practices (e.g., how frequently the bridge has been exposed to chemicals), and effects of flooding. The reason these other factors are not included in the model is because they cannot be readily measured or the data is not readily available.

3.7 Parameter Estimates and Standard Errors

The estimates from the substructure model and their corresponding standard errors are shown in Table 7. As shown in Column 3, the standard errors of most variables are small in relation to the estimated values. However, the standard errors may be suspect unless the variance of the regression is consistent over the entire range of the dependent variable.

In statistics, a collection of variables is heteroscedastic if the variables do not have the same variance. The issue of non-constant variance, or heteroscedasticity, is common in regression analysis. In most instances, the form of heteroscedasticity is unknown and cannot be ascertained from the data. In such cases, the variance is said to be inconsistent, meaning it is not a function of an independent variable and does not increase or decrease monotonically. The regression coefficients (i.e., the parameter estimates) are not biased by heteroscedasticity. However, there are two potential issues. (1) Regression coefficients estimated from sample data may no longer be efficient (e.g., minimum variance estimators). (2) The standard errors may be affected. As a result, hypothesis tests may be unreliable.

The first issue is not really a concern for this study because the parameters are estimated from population data. Nevertheless, as recommended by Hayes and Cai [8], heteroscedasticity-consistent errors are used to assess thepotential effects of inconsistent variance. These standard errors (shown in Column 6 of Table 7) are computed under the assumption that the variance is not constant.

The t statistic is computed by dividing the estimated value of the parameter by its standard error (t = parameter estimate/standard error). This statistic is a measure of the likelihood that the actual value of the parameter is not zero. The larger the absolute value of t, the less likely that the actual value of the parameter could be zero. The Pr. >|t| value is the probability of obtaining the estimated value of the parameter if the actual parameter value is zero. The smaller the value of Pr.>|t|, the more significant the parameter and the less likely that actual parameter value is zero.

The values shown in Column 2, 3, 4, and 5 are the ordinary least square (OLS) regression statistics, which assume constant variance or known as homoscedasticity. The values shown in Column 6, 7, and 8 are the heteroscedasticityconsistent regression statistics, which assume non-constant variance or known as heteroscedasticityand reduce the effects of heteroscedasticityon inference by employing a heteroscedasticity-consistent standard error estimator

Table 7 Parameter estimates and probabilities of national bridge substructure model.

Variable	Parameter Estimate	Standard Error	t Value	Pr. > |t|	Heteroscedasticity Consistent		
					Standard Error	t Value	Pr. > |t|
Intercept	8.37624	0.01311	639.09	<.0001	0.01192	702.76	<.0001
Reconstructed	0.28033	0.00475	59.00	<.0001	0.00509	55.06	<.0001
Water Crossing	-0.07514	0.00428	-17.56	<.0001	0.00382	-19.65	<.0001
Material							
Timber	-0.49083	0.00758	-64.73	<.0001	0.00957	-51.27	<.0001
Steel	-0.22225	0.00469	-47.34	<.0001	0.00451	-49.31	<.0001
Concrete							
Structure							
Beam	-0.05950	0.00639	-9.31	<.0001	0.00618	-9.62	<.0001
Girder	-0.03618	0.00603	-6.00	<.0001	0.00555	-6.52	<.0001
Stringer	-0.02205	0.00500	-4.41	<.0001	0.00480	-4.59	<.0001
Slab							
Design Load							
H_10	-0.20541	0.01072	-19.16	<.0001	0.01481	-13.87	<.0001
H_15	0.21019	0.00633	33.22	<.0001	0.00721	29.17	<.0001
H_20	0.28143	0.00688	40.88	<.0001	0.00740	38.01	<.0001
HS_15	0.27502	0.01119	24.58	<.0001	0.01198	22.95	<.0001
HS_20	0.36023	0.00540	66.66	<.0001	0.00588	61.28	<.0001
HS_20+	0.30037	0.00698	43.03	<.0001	0.00703	42.71	<.0001
HS_25	0.39663	0.00951	41.71	<.0001	0.00911	43.55	<.0001
Other							
Op. Rating							
≤ 20 tons	-0.94360	0.00727	-129.76	<.0001	0.01051	-89.75	<.0001
≤ 30 tons	-0.35199	0.00704	-50.02	<.0001	0.00821	-42.89	<.0001
≤ 40 tons	-0.09150	0.00490	-18.69	<.0001	0.00515	-17.78	<.0001
> 40 tons							
ADT Class							
0-100	0.08893	0.00686	12.96	<.0001	0.00637	13.97	<.0001
101-1,000	0.13321	0.00629	21.17	<.0001	0.00560	23.77	<.0001
1,001-5,000	0.09758	0.00615	15.88	<.0001	0.00530	18.40	<.0001
5,000-19,000	0.03866	0.00588	6.58	<.0001	0.00494	7.83	<.0001
> 19,000							
Age	-0.08444	0.00099948	-84.48	<.0001	0.00093242	-90.56	<.0001
Age^2	0.00139	0.00003811	36.42	<.0001	0.00003763	36.89	<.0001
Age^3	-0.00001337	5.390358E-7	-24.80	<.0001	5.559425E-7	-24.04	<.0001
Age^4	5.33248E-8	2.508156E-9	21.26	<.0001	2.68578E-9	19.85	<.0001
State							
AK	-0.24860	0.03145	-7.90	<.0001	0.04357	-5.71	<.0001
AL	-0.08251	0.01271	-6.49	<.0001	0.01148	-7.19	<.0001

To be continued

Continued

AR	0.14248	0.01362	10.46	<.0001	0.01200	11.87	<.0001
AZ	-0.10406	0.01950	-5.34	<.0001	0.01701	-6.12	<.0001
CO	-0.19672	0.01126	-17.48	<.0001	0.00957	-20.56	<.0001
CT	-0.27745	0.01843	-15.06	<.0001	0.01595	-17.40	<.0001
DC	-0.27188	0.07556	-3.60	0.0003	0.06914	-3.93	<.0001
DE	-0.46873	0.04080	-11.49	<.0001	0.03183	-14.72	<.0001
FL	-0.09118	0.01255	-7.27	<.0001	0.00982	-9.28	<.0001
GA	-0.35534	0.01252	-28.39	<.0001	0.01153	-30.83	<.0001
HI	0.15139	0.03310	4.57	<.0001	0.02978	5.08	<.0001
IA	-0.32161	0.01029	-31.26	<.0001	0.01030	-31.21	<.0001
ID	-0.46769	0.01830	-25.56	<.0001	0.01977	-23.66	<.0001
IL	0.05499	0.00988	5.57	<.0001	0.00862	6.38	<.0001
IN	-0.30917	0.01058	-29.23	<.0001	0.00915	-33.80	<.0001
KS	0.16030	0.01057	15.17	<.0001	0.00974	16.46	<.0001
KY	-0.32335	0.01195	-27.06	<.0001	0.01112	-29.07	<.0001
LA	-0.28424	0.01203	-23.63	<.0001	0.01348	-21.09	<.0001
MA	-0.27870	0.01700	-16.39	<.0001	0.01595	-17.47	<.0001
MD	-0.47123	0.01785	-26.39	<.0001	0.01439	-32.75	<.0001
ME	-0.24353	0.02337	-10.42	<.0001	0.02342	-10.40	<.0001
MI	-0.22662	0.01227	-18.47	<.0001	0.01230	-18.42	<.0001
MN	-0.16077	0.01353	-11.88	<.0001	0.01372	-11.72	<.0001
MO	0.34109	0.01044	32.68	<.0001	0.00975	34.99	<.0001
MS	0.08470	0.01318	6.43	<.0001	0.01425	5.94	<.0001
MT	0.06077	0.01624	3.74	0.0002	0.01581	3.84	0.0001
NC	-0.28434	0.01138	-24.99	<.0001	0.01068	-26.62	<.0001
ND	0.04686	0.02071	2.26	0.0236	0.02401	1.95	0.0510
NE	0.51367	0.01188	43.24	<.0001	0.01220	42.09	<.0001
NH	0.17189	0.02415	7.12	<.0001	0.02517	6.83	<.0001
NJ	-0.30251	0.01504	-20.11	<.0001	0.01230	-24.59	<.0001
NM	-0.88481	0.02217	-39.91	<.0001	0.02152	-41.12	<.0001
NV	-0.26525	0.02359	-11.24	<.0001	0.01728	-15.35	<.0001
NY	-0.22312	0.01116	-20.00	<.0001	0.01116	-19.99	<.0001
OH	0.04124	0.00945	4.36	<.0001	0.00878	4.70	<.0001
OK	-0.72676	0.01076	-67.56	<.0001	0.01159	-62.72	<.0001
OR	-0.30992	0.01411	-21.96	<.0001	0.01427	-21.72	<.0001
PA	-0.79479	0.01156	-68.76	<.0001	0.01152	-69.00	<.0001
RI	-0.95154	0.04017	-23.69	<.0001	0.04058	-23.45	<.0001
SC	-0.40671	0.01322	-30.77	<.0001	0.01265	-32.16	<.0001
SD	-0.51615	0.01640	-31.48	<.0001	0.01621	-31.84	<.0001
TX	-0.41609	0.00912	-45.65	<.0001	0.00755	-55.15	<.0001
UT	-0.11995	0.02257	-5.31	<.0001	0.01986	-6.04	<.0001
VA	-0.34138	0.01213	-28.15	<.0001	0.01112	-30.71	<.0001

To be continued

Continued

VT	-0.00301	0.02123	-0.14	0.8873	0.02206	-0.14	0.8915
WA	-0.07969	0.01416	-5.63	<.0001	0.01236	-6.45	<.0001
WI	-0.17566	0.01157	-15.18	<.0001	0.01031	-17.03	<.0001
WV	-0.29327	0.01507	-19.47	<.0001	0.01473	-19.91	<.0001
WY	-0.34206	0.02055	-16.65	<.0001	0.01841	-18.58	<.0001
CA							

of OLS parameter estimates. A comparison of Columns 4 and 7 shows only modest differences between the t values, suggesting mild inconsistency. Onlyone of the hypothesis tests is affected, based ona probability threshold of 0.05.

3.8 Probability Values and Inferences

The NBI database constitutes the inventory or population of publicly-owned bridges in the United States. Because an inventory is available, sampling variability is not an issue. Nevertheless, it is beneficial to envision the NBI as a large sample of bridges that do (or could) exist. This visualization allows hypothesis tests that provide intuitive insights concerning the statistical significance of particular effects. For each variable, the null hypothesis is that the partial effect attributable to the variable is statistically insignificant. This means that the intercept shift attributable to the variable is not significantly different from zero. For quantitative variables, the null hypothesis is that the partial slope coefficients are not significantly different from zero.

The probability values (or p-values) associated with the t statistics are shown in Columns 5 and 8 of Table 7, respectively. With two exceptions, the p-values in Column 8 indicate that the estimated independent variables' parameters are highly significant and are not equal to zero (i.e., values of < .01). The p-values of71 of the variables in the model are < 0.0001, indicatingless than a 1in 10,000 chance of observing t values as large as those observed. However, the large p-value of 0.89 for Vermont (variable name is coded as VT) indicates that the intercept for this state is not significantly different from the model intercept, which implies that the interceptsofVermont and California (the state left out of the model) are not statistically different. The p-value of 0.051 for North Dakota is marginally significant (i.e., < 0.10).

As shown in Table 7, the parameter estimates of Age, Age^2, Age^3, and Age^4 are highly significant. If any of the terms of the polynomial were unimportant, the probability values associated with the tratios would be much higher. The negative sign of age indicates that bridge condition rating decreases with age. The positive sign of age squared indicates that the rate of deterioration is not linear and will slow with age — i.e., when bridges reach advanced ages, such as 65. The negative and positive signs associated with Age^3 and Age^4 indicate that the regression surface turns up and down again, as illustrated in Fig. 5.

3.9 Class Variable Effects

In this section, the interpretation of the estimated parameters associated with material, structural typestructural, design load, operation rating, and an ADT class is introduced.

In the regression model, the effect of a class level is interpreted in relation to the base level subsumed in the intercept. As shown in Table 7, the parameter estimates of steel, timber, and other bridges have negativesigns, indicating that these bridges deteriorate at faster rates than concrete bridges (ceteris paribus). Moreover, the larger negative coefficient of timber indicates that the expected condition ratings of timber bridges are lower than the expected condition ratings of steel bridges. These results are consistent with the findings of Dunker and Rabbat [6].

The coefficients of stringer, tee-beam, and boxgirder bridges are negative in relation to slab bridges, indicating that slab bridges are expected to have higher condition ratings than other types of structures. These results are consistent with the findings of Kim and Yoon [5].

The coefficients of H-15, H-20, HS-15, HS-20, HS-20$^+$, and HS-25 bridges are positive, meaning that substructure ratings should be higher over time for these designs than for bridges included in the "other" category. The greatest positive effects are associated with HS-25, HS-20, and HS-20$^+$ bridges, respectively. The only negative sign is associated with H-10, which indicates that these bridges (which have the lowest load ratings) are expected to deteriorate at faster rates than bridges included in the "other" category.

The signs of the operating rating variablesare negative and must be interpreted in relation to bridges with operating ratings > 40 tons. The negative signs suggest that bridge substructure rating is expected to decrease with operating rating. This is because the operating rating is a reflection of the capability of a bridge to accommodate modern truck traffic.The relative magnitudes of the coefficients make sense too, because the magnitudes of the effects increase as the operating ratings decline. However, the difference between bridges with operating ratings of 30.1 to 40 tons and bridges with operating ratings > 40 tons is relatively small.

The signs of the ADT class variables (0–100; 101–1,000; 1,001–5,000; and 5001–19,000 vehicles per day) are positive in relation to the base level (> 19,000 vehicles per day), suggesting that traffic contributes to loss of condition rating over time. Similarly, the negative sign of waterspan indicates that exposure of bridge piers and foundations to water results in lower predicted values of condition. However, the positive sign of reconstruction indicates that, after reconstruction, a bridge's condition rating jumps. In the regression model, this effect is reflectedin the intercept shift attributable to reconstruction.

3.10 Multicollinearity

Multicollinearity exists when one or more of the independent variables are highly correlated with each other. In multiple regression analysis, multicollinearity is a question of degree. However, extensive multicollinearity may create issues. (1) The standard errors of the estimates may become inflated. As a result, hypothesis tests may be unreliable. Because of inflated errors, a variable that is actually important may fail a hypothesis test. (2) The estimates of the parameters may be conditional upon other variables. Consequently, the parameter estimates of several variables may change if a highly correlated variable is dropped from or added to the model.

Multicollinearitycan be assessed throughthe variance inflation factor (VIF), which is computed by regressing one independent variable against all others and using the R^2 from that regression. Opinions vary widely about in what degree ofmulticollinearity can be tolerated. One suggestion is that variables with VIFs greater than 10 may indicate problems. Other, more conservative ideas, suggest that VIFs greater than 5.0 should be investigated. The VIF scores of the 70 independent variables associated with the eight effects range from 1.01 to 4.18 with a median value of 1.48, suggesting relatively low levels of multicollinearity. As shown in Table 8, the parameter estimate of age is relatively robust with respect to the dropping or exclusion of effects.

As shown in Table 7, the coefficient of age is -0.08444. For purposes of comparison, revised estimates of age after dropping the main effects one at a

Table 8 Sensitivity of age to main effect variables.

Excluded Effect	Parameter Estimate of Age	Percent Change in Estimate
State	-0.08430	-0.2%
Design Load	-0.08401	-0.5%
Bridge Material	-0.08342	-1.2%
ADT Class	-0.08402	-0.5%
Operating Rating	-0.08182	-3.1%
Structural Type	-0.08471	0.3%

time are shown in Column 2 of Table 8. The percentage change as a result of each dropped effect is listed in Column 3. As the table shows, the largest change would occur if the operating ratingis dropped from the model. Perhaps this is because very old bridges tend to have lower operating ratings. The second largest change would result from dropping bridge material, suggesting there is some collinearitybetween the age of structures and the material used. This could be attributable to a shift in construction materials over time from timber to concrete and steel.

The main inferences from these illustrations are (1) without controlling for operating rating and bridge material, the parameter estimate of age would be biased, and (2) multicollinearity is relatively low, making the estimate of age somewhat robust. The practical inference of this discussion is that none of the variables should be dropped from the model because, in doing so, information would be lost.In general, the omission of relevant variables results in biased coefficient estimates for the explanatory variables left in the model [9].

3.11 Model Forecast

Because the predictions are ratio scaled, they include fractional results. In effect, they provide information about when a bridge is in transition from one condition level to the next. For example, a bridge with a predicted condition rating of 6.8 is likely to stay in satisfactory condition for several years. In contrast, a bridge with a predicted condition rating of 6.05 is on the verge of transitioning from satisfactory to fair.

All of the indicator variables must be included in a forecast because the effect attributable to a coefficient (e.g., H-20 bridges) reflects all of the base levels of the other indicator variables subsumed in the intercept — e.g., a concrete slab bridge in California with an operating rating >40 tons that has not been reconstructed and does notspan water. If the levels of any of the indicator variables change from their bases, these effects must be included in the forecast. For example, if an H-20 bridge is built with steel, the coefficients of H-20 and steel must be added to the intercept to create an adjusted intercept. The forecasting process is illustrated for an HS-20 box girder steel bridge in New York that has never been reconstructed, spans a body of water, has an operating rating > 40 tons,and average daily traffic of 15,000 vehicles. The specific intercept is computed as $8.37624-0.07514 - 0.22225- 0.03618+ 0.36023 + 0.03866 - 0.22312 \approx 8.22$. Seven terms are reflected in this calculation: the model intercept (8.37624), the New York intercept shift (-0.22312), the material type intercept shift (-0.22225), the bridge design intercept shift (0.36023), the structure intercept shift (-0.03618), the water crossing intercept shift (-0.07514) and the ADT intercept shift (0.03866). There is no adjustment factor or shift for operating rating. This is because operating rating of > 40 tons serves as the base operating rating of the model. Moreover, there is no intercept shift for reconstruction.

In this process, the parameter estimate of each class variable is added to the intercept to compute a specific intercept for the type and design of bridge and traffic class within the state of interest. In this example, a new HS-20 steel bridge is predicted to have a condition rating of 6.35 after 40 years. In other words, the bridge is expected to be in satisfactory condition with only minor problems.The condition ratings over time for this example are shown in Fig. 6.

The change in substructure condition can be estimated for small changes in age by taking the partial derivative of the function. However, the rate of bridge deterioration during any year is relatively small. Instead of using the derivative, Fig. 7 shows the projected rates of condition loss for bridges by decade from 10 to 100 years, as estimated from the model. The chart resembles a portion of the curve shown earlier in Fig. 5. Because of the polynomial form, the rate of condition loss varies with age. A bridge loses 0.52 rating points during the second decade of existence. However, the rate of loss drops to 0.37, 0.27, and 0.21 in the third, fourth, and fifth decades, respectively. The expected rates of decline are 0.17, 0.11, and 0.08 for

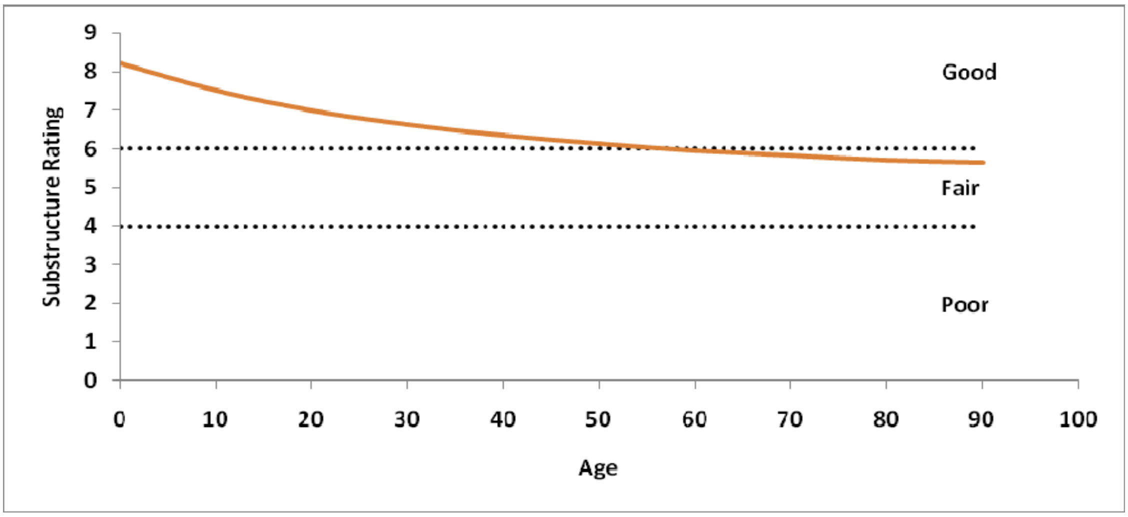

Fig. 6 Substructure ratings versus age for HS-20 Box Girder Steel Bridge in New York.

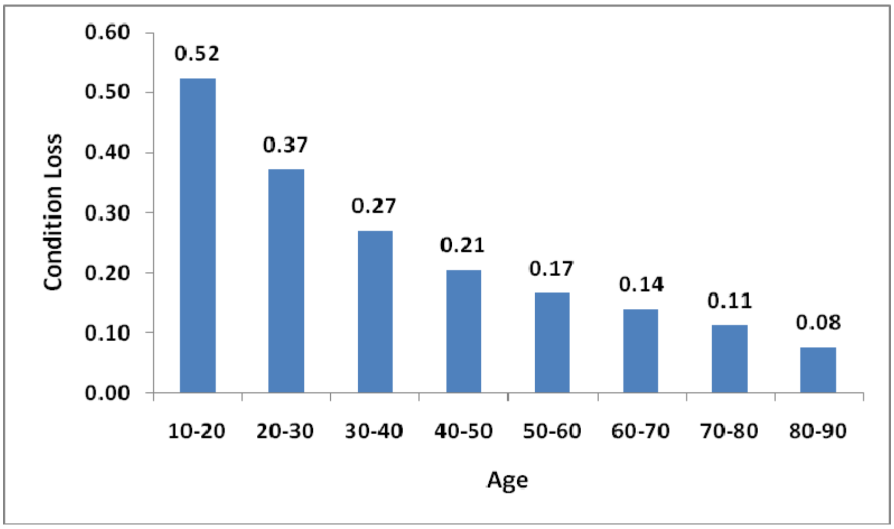

Fig. 7 Rate of expected bridge substructure condition loss by decade.

bridges in their sixth, seventh, and eighth decades of life, respectively.

4. State-Level Model

While the national model could be used to forecast condition ratings within a particular state, its primary value is to provide strategic information for policy and funding considerations. More specific forecasts of bridge conditions can be derived from a state-level model, which is illustrated for Iowa—a state located in the north-central region of the United States.

As would be the case with any state, Iowa has some unique characteristics that warrant adjustments to the national model. Only four of Iowa's bridges are in the HS-25 category. These observations are deleted due to insufficient **numbers**. Less than 0.5% of the observations fall into the H-10 and H-15 categories. For statistical reasons, these classifications are combined into one category.The traffic levels are much lower in Iowa than in more populatedregions. Approximately 50% percent of the bridges carry less than 60 vehicles per day. Given the large percentage of bridges with low traffic volumes, ADT is highly collinear with other variables and has a weak effect. Therefore, it is dropped from the model. In addition, the highway district variable is substituted for the state indicator. With these modifications, the remaining variables are the same as in the national model. Although the F-tests for the remaining effects are highly significant, a third-order polynomial fits the Iowa data better than a fourth-order model.

With an R^2 of 0.637, the Iowa model explains nearly 64% of the variation in substructure condition rating withinthe state. As shown in Table 9, all but two of the variables in the model are statistically significant with p-values of < 0.05, including the sub-state district variables. The VIF scores of the effect variables range from 1.02 to 3.09 with a median value of 1.79. The exclusion ofADT from the model drops the R^2 slightly, from 0.6376 to 0.6370, indicating that traffic is not a significant explanatory variable, given the high proportion of bridges with low traffic volumes.

The signs of the design load categories are all positive. As expected, HS-20 and HS-20^+ bridges show the greatest increases in condition ratings relative to other bridges, and the coefficient of H-20 bridges is

Table 9 Parameter Estimates and Probabilities of Iowa Bridge Substructure Model.

Variable	Parameter Estimate	Standard Error	t Value	Pr. > |t|
Water Crossing	-0.12521	0.02969	-4.22	<.0001
Material				
Timber	-0.50655	0.02928	-17.30	<.0001
Steel	-0.24036	0.02237	-10.74	<.0001
Concrete				
Structural Type				
Beam	-0.43045	0.03350	-12.85	<.0001
Stringer	-0.00281	0.02226	-0.13	0.8995
Slab				
Design Load				
H-10/H-15	0.22460	0.02449	9.17	<.0001
H-20	0.39009	0.02722	14.33	<.0001
HS-15	0.36686	0.11538	3.18	0.0015
HS-20	0.51128	0.02743	18.64	<.0001
HS-20^+	0.71507	0.07222	9.90	<.0001
Other				
Op. Rating				
≤ 20 tons	-1.20902	0.03235	-37.38	<.0001
≤ 30 tons	-0.40276	0.02688	-14.98	<.0001
≤ 40 tons	-0.01122	0.02010	-0.56	0.5769
> 40 tons				
Age	-0.10687	0.00243	-43.99	<.0001
Age^2	0.00107	0.00005336	20.12	<.0001
Age^3	-0.00000347	3.238061E-7	-10.72	<.0001
District				
1				
2	0.06306	0.02602	2.42	0.0154
3	0.14217	0.02596	5.48	<.0001
4	-0.17984	0.02606	-6.90	<.0001
5	-0.16648	0.02697	-6.17	<.0001
6	0.14587	0.02704	5.39	<.0001

greater than the coefficient of H-10/H-15 bridges. The coefficients of timber and steel are similar to the coefficients of those variables in the national model. In addition, the signs of structural type and operating rating are the same as in the national model; however, “stringer” is not statistically significant, indicating that the intercepts for stringer and slab bridges in Iowa are essentially the same. Moreover, there is no significant difference between bridges with operating ratings of 30.1 tons to 40 tons and bridges with operating ratings > 40 tons.

In the national model, the state variable controls for climatic, geographic, political, financial, and jurisdictional differences among states. At the state level, the highway district indicator variable serves a similar purpose, controlling for variations within the state. While temperature and moisture may vary within a state, the differences are relatively small compared to variations ona national scale. The advantage of the state model is homogeneity of conditions.

5. Conclusion

A national model for estimating substructure deterioration rates has been developed which has good statistical properties: e.g., a large F-value with many highly significant parameters, low multicollinearity, very mild heteroscedasticity, and a relatively low coefficient of variation. This model is appropriate for system and subsystem planning, in which the objective is to provide agency managers and policy makers with strategic information: e.g., the expected condition levels of subsets of bridges. However, a more specific forecasting model can be developed for each state using NBI data and the procedures described in this paper. However, in doing so, some adjustments to category levels and variables may be necessary.At the state level, it is possible to supplement NBI data with local climate data from nearby weather stations [5], which may reflect local climatological differences more specifically than the highway district indicator variable.

The relationship between age and substructure condition is a fourth-order polynomial. Some of thekey findings are (1) a bridge substructure is expected to lose from 0.52 to 0.11 rating points per decade as it ages from 10 to 70 years; (2) levels of deterioration increase significantly as the material changes from concrete, to steel, to timber; (3) slab bridges have lower levels of deterioration than other structures; (4) bridges that span water have lower condition ratings; (5) bridges with higher operating ratings have higher condition ratings; and (6) substructure condition ratings vary significantly among states.

In conclusion, it is important to summarize some of the key assumptions and information not available for this study. (1) The history and timing of maintenance expenditures for the life of each bridge are unknown. (2) The condition ratings are scored by different people. As a result, human variations are reflected in the evaluations.(3) Many individual bridge effects, such as the frequency of unusual loadings, deicing practices, and initial and extreme conditions are not reflected in the models.(4) Because only current ADT values are known, traffic is treated as a categorical (rather than a continuous) variable. Nevertheless, the ADT classification of a bridge may have shiftedover time as a result of very large traffic changes. (5) The analysis includes only stringer, tee-beam, slab, boxgirder, concrete, timber, and steel bridges, while excluding culverts. (6) The results are specific to the types of bridges analyzed.

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State Representation Methodology (SRM) for Bridge Condition Assessment in SHM

Ayaho Miyamoto[1] and Akito Yabe[2]

1. Graduate School of Science & Engineering, Yamaguchi University, Ube, Japan

2. Seismic Engineering Department., KOZO KEIKAKU Engineering Inc. Tokyo, Japan

Abstract: This paper introduces a new concept of "State Representation Methodology (SRM)" which is a kind of bridge condition assessment method for structural health monitoring system (SHM). There are many methods for system identification from the simplicity comparison of damage index to the complicated statistical pattern recognition algorithms in SHM. In these methods, modal analysis and parameters identification or many defined indices are common-used for extracting the dynamic or static characteristics of a system. However, there is a common problem: due to the complexity of a large size system with high-order nonlinear characteristics and severe environment interference, it is impossible to extract and quantify exactly these modal parameters or system parameters or indices as the feature vectors of a system in damage detection in an easy way. The SRM considered a more general theory for the non-parametric description of system state.

Key words: Bridge, damage detection, system state representation methodology (SRM), structural health monitoring (SHM), state representation function (SRF), SRM Tool, Kernel function.

1. Introduction

In recently, structural health monitoring (SHM) has received an increasing attention in the field of deteriorating civil infrastructures, such as bridges, highway networks, etc [1]. Meanwhile, the condition assessment is becoming one of the most important issues in this field. A large size structure such as bridges produces a huge amount of monitoring data for every day, every month and every year. It becomes also an important thing that how to detect damages from such huge number of monitoring data, that is a big challenge for analysis to discover the damage information of a target structure. Furthermore, there are not only many kinds of sensor data, but also many undetermined factors in the system, such as the dynamic loads, ever-changing climate condition, and severe noise interference. At the same time, we cannot exactly find a model to describe any structure and a variety of data interrelationship in design stage or during any operating period. In generally, the large structure can be viewed as a system, and the large-scale systems theory or any other new methods can be employed to research the system. It is obvious that those large systems are a high-order nonlinear system. The nature exists a great of complex systems, many of them have some similar or not. At least, the description of a system state is an essential problem, and even a philosophical methodology problem [2].

Fig. 1 shows that how important the condition assessment in SHM research. It is easy to understand from this figure that the practical condition assessment is still a basic problem in SHM research, although there are many literatures to study on the topics for SHM. In this paper, it will be focusing on to try to easy explanation of the analysis methods of condition assessment in SHM with comparison between traditional methods and a new proposed method which called "Sate Representation Methodology (SRM)" [3, 4]. Then the main content of the paper is consisted

Corresponding author: Ayaho Miyamoto, PhD, professor, research fields: bridge engineering, structural concrete engineering, advanced systems engineering. E-mail: miya818@yamaguchi-u.ac.jp.

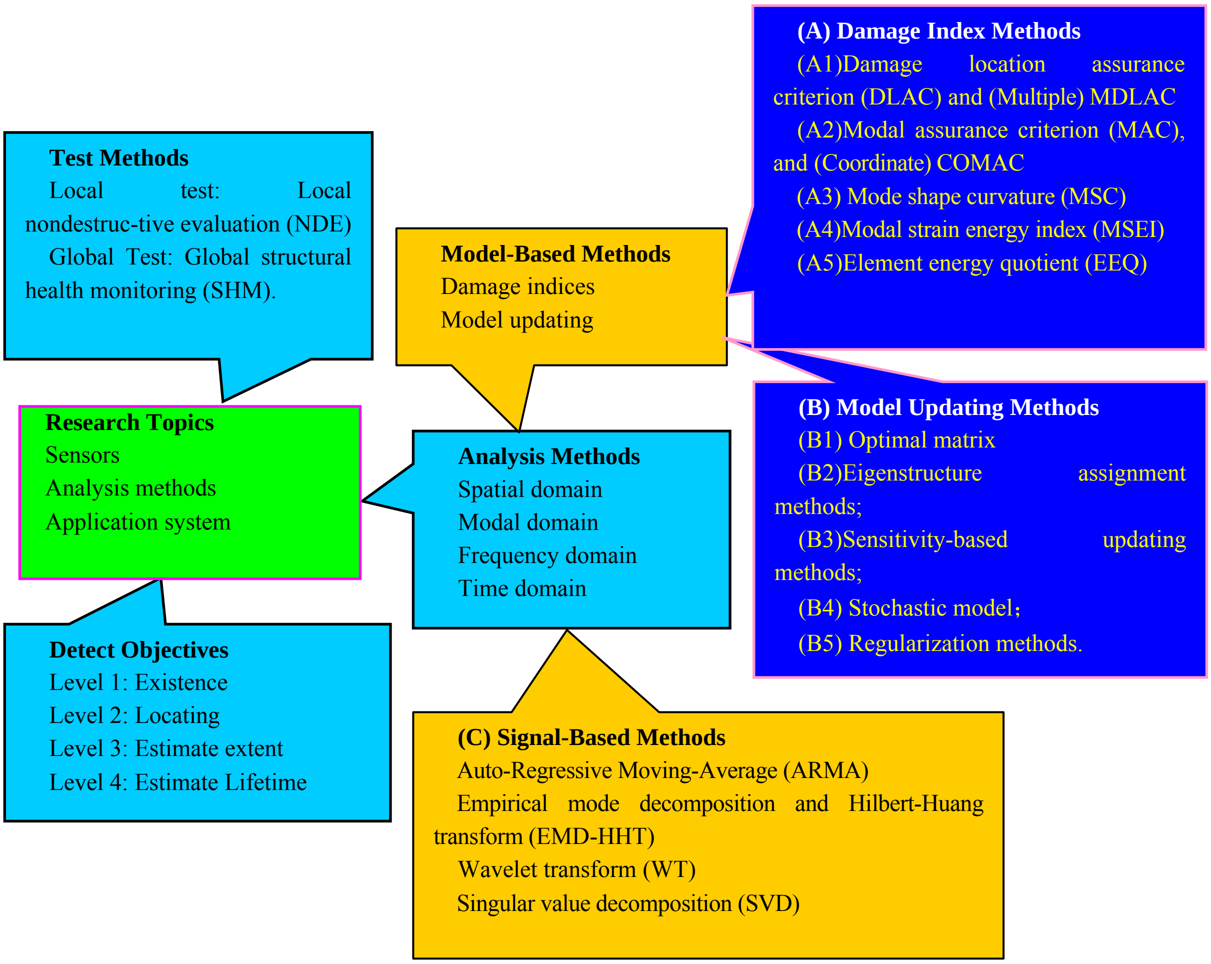


Fig. 1 Data analysis methods for condition assessment in SHM research.

from the basic theory (concept) of "Sate Representation Methodology (SRM)" to its applications to practical "Condition Assessment" for bridge structures.

2. SRM Concept Based on Kernel Function Method

2.1 What is the SRM?

Here, we will be focusing on the structural health monitoring system (SHMS). Especially, how do we describe the probability state from the structure monitoring data? In another view, can we know more about what's happened & when the monitored signals have been changing, and what is the relationship between the system state and the sensor's signals? All of those about detecting and locating are very important for a practical SHMS. In this paper, we will be able to give a new idea and systemic methods to describe and assess the structural state which called as the system State Representation Methodology (SRM) [2, 3]. Based on theoretical research of the SRM, we developed a systemic method to describe damage feature and state of structural system.

In a complex system such as bridge structures, it comes some common and basic questions as follows:

(1) What is the present state of a system?

(2) How is it possible to build a model to describe the system state?

(3) How is it possible to compare the state change of the system?

(4) How is it possible to extract the state features of the system?

(5) What kind of damages are occurring in the system?

(6) How is it possible to locate a damage of the system?

2.2 What is the State of a System?

The state of a system is interpreted as the overall response to its internal and external factors which essentially depend on the response of structure itself or structural properties and nature environment. Then, the quantitative assessment of the system state is the description for system responding to the exciting factors. If the responses satisfy the suitable values, the system state is considered as normal state, otherwise as abnormal (damaged) state. In usually circumstances or under normal use conditions, the system is in stable state, this means its state should be a constant, or fluctuation near a steady state. In general sense, we therefore assume that it is a steady random variable and it is usually obeyed the normal distribution.

Assumption: The state of a system is a function of the system response to environmental exciting.

Obviously, this assumption has so natural sense. Nevertheless, we cannot use the response data directly in time domain because it is obvious time-varying signal. Therefore, we usually translate into the frequency domain or other transformation domain. This process is called features extracting. Fig. 2 shows the procedure of feature extracting, in where x is called the system feature vector, ζ is the state variable, λ is the system structure alias parameter. Therefore the state of a system can be described by the variable ζ, and it should be a function about the system features that can be extracted from the responses to its various factors. In fact, the successful use of the SRM depends on the experimenter's ability to develop a suitable approximation for the system state function $f(\cdot)$, which it is called "State Representation Function (SRF)". The SRF can be written as,

$$\zeta = f(\lambda, x) = 1 \quad (1)$$

The SRM tools mentioned in Fig. 2 will be introduced in Ref. [4].

2.3 System State Approximating

Fig. 3 shows a basic idea for state variable expression by approximating methods. The following

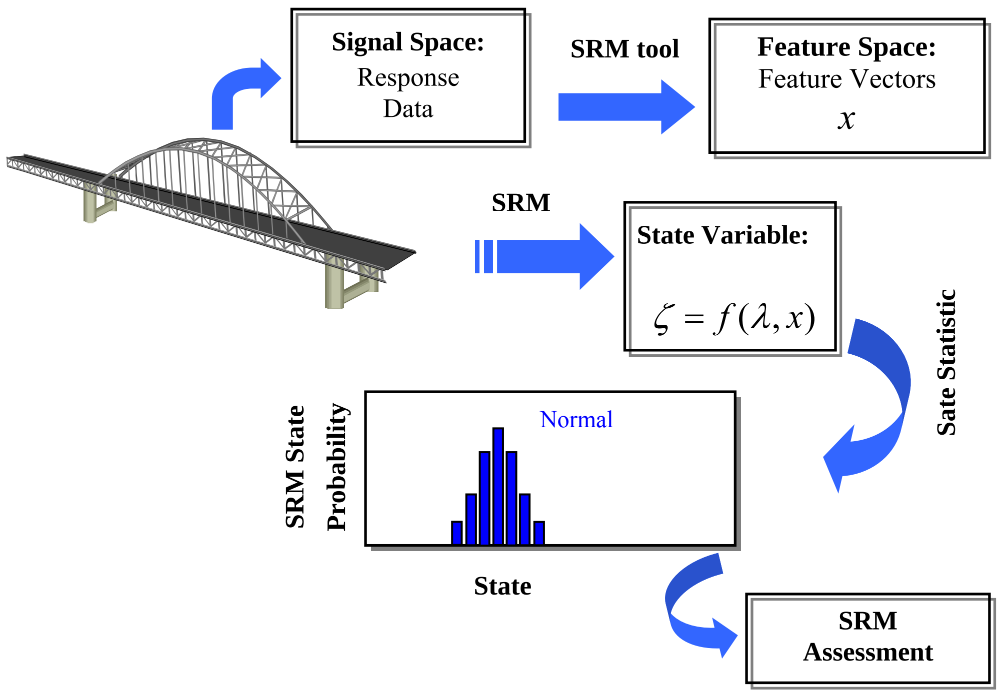


Fig. 2 SRM conceptual model.

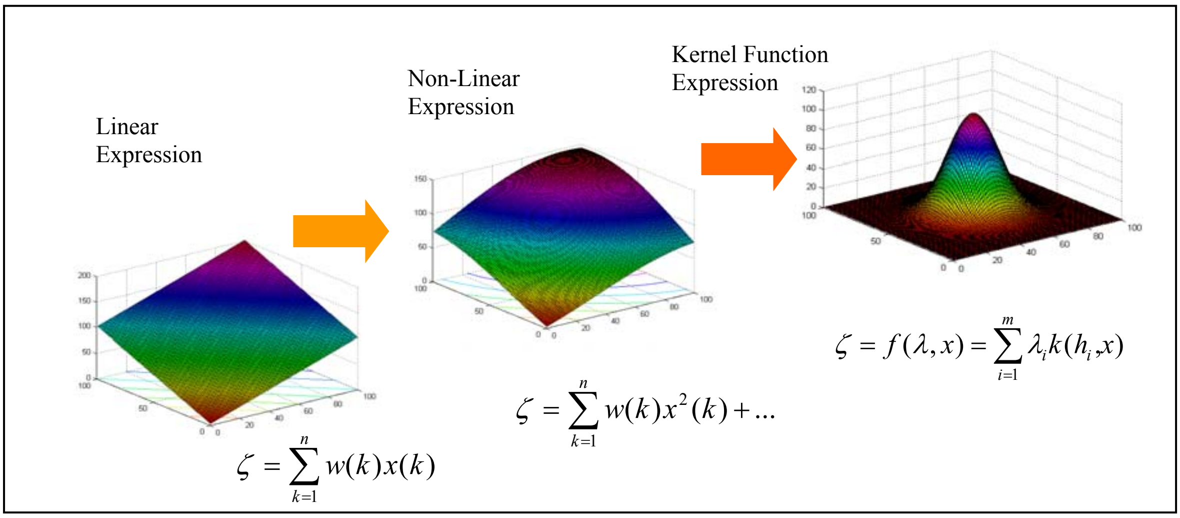


Fig. 3 Schematic diagram of approximating the state variable.

will analyze the main idea of the Kernel Function expression.

Let w is constant vector in R^n, called as system state support vector which is related to the system structure parameters, we take the first-order model to approximate the Eq. (1) as the following:

$$1 = < w, x > = \sum_{k=1}^{n} w(k)x(k) \tag{2}$$

Use the Least Squares Estimators (LSE) method, it is easy to get the weight vector w; if the system has only one response feature vector h in its initial feature space (*IFS*), i.e. we assume that $h \in IFS \subset R^n$, the least squares solution of Eq. (2) should be:

$$w = \frac{h}{\|h\|^2} \tag{3}$$

However, we respectively take m feature vectors of *IFS*, the least squares solution respectively should be:

$$w_i = \frac{h_i}{\|h_i\|^2}, i = 1,2....m \tag{4}$$

Now let us consider every response feature vector $h \in IFS$ as a projector of the current system state along with each feature direction, then we give them with a weight: $\lambda_i \geq 0$ and

$$\lambda_i \in (0,1), \sum_{i=1}^{m} \lambda_i = 1,$$

$$w = \sum_{i=1}^{m} \lambda_i w_i = \sum_{i=1}^{m} \alpha_i h_i, \quad \alpha_i = \frac{\lambda_i}{\|h_i\|^2} \geq 0$$

Then,

$$1 = < w, x > = < \sum_{i=1}^{m} \alpha_i h_i, x > = \sum_{i=1}^{m} \alpha_i < h_i, x > \tag{5}$$

One can define a function included parameter vector α, as:

$$f(\alpha, x) = \sum_{i=1}^{m} \alpha_i < h_i, x > \tag{6}$$

Eq. (6) is called the first-order representation function of system state, it's a linear operator, where vector α is also called as system alias parameter or system state parameter, which is relative with the system structure. Note that Eq. (6) can be rewritten as,

$$f(\lambda, x) = \sum_{i=1}^{m} \lambda_i \frac{\|x\|}{\|h_i\|} < \frac{h_i}{\|h_i\|}, \frac{x}{\|x\|} > \quad \sum_{i=1}^{m} \lambda_i = 1, \ \lambda_i \geq 0 \tag{7}$$

If $\|h_i\| = \|x\|$ is always assumed, then we have,

$$f(\lambda, x) = \sum_{i=1}^{m} \lambda_i < \frac{h_i}{\|h_i\|}, \frac{x}{\|x\|} > \quad \sum_{i=1}^{m} \lambda_i = 1, \ \lambda_i \geq 0 \tag{8}$$

Then,

$$f(\lambda, x) \leq 1 \quad \text{for always} \tag{9}$$

Let $\overline{w} = \sum_{k=1}^{m} \lambda_k \frac{h_k}{\|h_k\|}$, then Eq. (8) can be rewritten as:

$$f(\overline{w}, x) = < \overline{w}, \frac{x}{\|x\|} > \tag{10}$$

The inner product < . > can be replaced by a Kernel Function form as follows. In generally, we can redefine $< s, x >, s \in X, x \in X$ as,

$$< s,x >=< \phi(s),\phi(x) >= k(s,x), s \in X, x \in X \quad (11)$$

where, X is a vector space. Here $k(s,x) =< \phi(s),\phi(x) >$ is called a Kernel Function. There are many choices for a Kernel Function $k(\cdot,\cdot)$. Here, the following Kernel Functions are recommended in [3, 5].

$$k(s,x) = \exp(-\frac{d(s,x)}{\sigma^2}) \quad (12)$$

here,

$$d(s,x) = \sum_{i=1}^{n} \frac{(s_i - x_i)^2}{s_i + x_i} \quad \text{or} \quad d(s,x) = (\sum_{i=1}^{n} |s_i - x_i|^p)^{1/p}$$

$$k(s,x) = (s \cdot x)^d, \ (\|s\| = 1, \|x\| = 1) \quad (13)$$

Note that σ is called the SRM scale. In fact, the difference between two any objects is absolute on any scales, but their similarity is relative on any scale. Therefore, scale concept is important to study the difference between two states of a system. Subsequently, we can get state function in the Kernel Function form:

$$\zeta = f(\lambda,x) = \sum_{i}^{m} \lambda_i k(h_i,x)$$

In order to satisfy that state should be a constant, we are able to define the following objective function:

$$\min \left\| (I - \frac{1}{m} ee^T) G\lambda \right\|^2$$
$$\text{Subject to} \quad \sum_i \lambda_i = 1, 0 \le \lambda_i \le 1, i = 1,2,3,....\text{m} \quad (14)$$

here,
$$G = \begin{pmatrix} k(h_1,h_1),k(h_1,h_2),....k(h_1,h_m) \\ k(h_2,h_1),k(h_2,h_2),....k(h_2,h_m) \\ \cdots\cdots\cdots\cdots\cdots\cdots \\ k(h_m,h_1),k(h_m,h_2),....k(h_m,h_m) \end{pmatrix}$$

Then, we can get state function as following:

$$\zeta = f(\lambda,x) = \sum_{i}^{m} \lambda_i k(h_i,x)$$

Eq. (14) can be illustrated as Fig. 4, where c is constant for a system, and $c = \frac{1}{m} e^T G\lambda$. We can get the alias parameter λ of system structure, which is also called as the support vector in SVM.

Let the system be in state ζ in current time with feature vector x, i.e., $\zeta = f(\lambda,x)$. ζ has different value with different feature vector x because of the system complexity. We may not know how many state values a system has, but we usually assume ζ to be a normal probability distribution. Many statistics methods can be performed to estimate the probability distribution. Therefore, we can use in variety of statistic tests such as F-test and t-test etc. to assess the difference between "virgin" state and "damaged" state in the past time. By using a laboratory bridge monitoring system (LBMS) (see [6]) to verify the SRM, experiments show that the SRM is available and steady to express the system state.

2.4 How Differences between the Existing Methods and the SRM?

Fig. 5 shows that traditional methods based on frequency domain decomposition (FDD) are widely recognized as a simple method [6]. However, it tends to often lead to the loss of sensitivity and accuracy of damage detection, because the power spectrum of the measured responses could not be accurately estimated, particularly for high-damped systems and systems with severe modal interference and high noise.

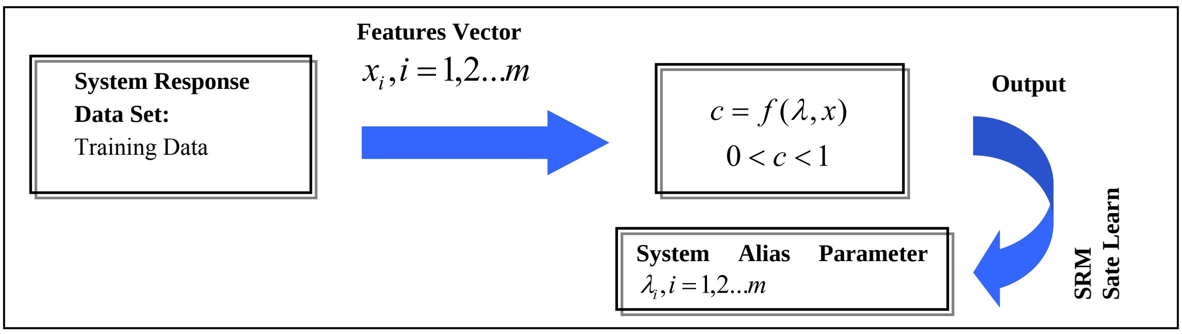


Fig. 4 Learning process in SRM.

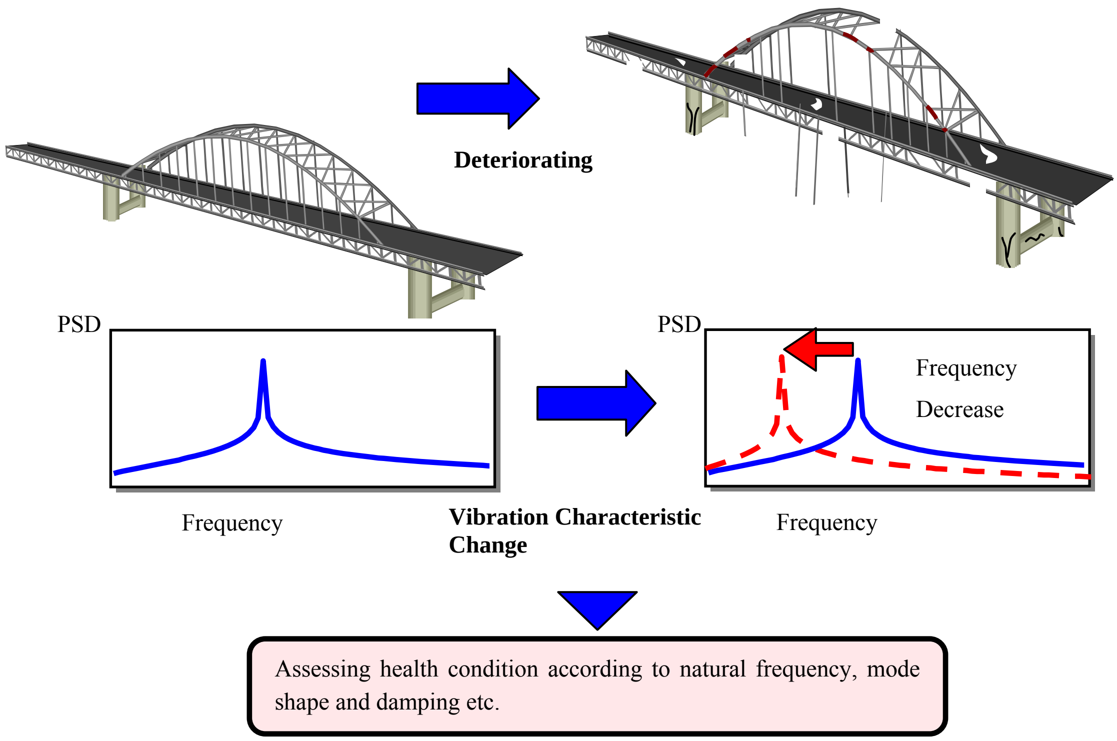


Fig. 5 Frequency domain decomposition (FDD) principle.

Meanwhile, there are some important questions in it: The natural frequency, corresponding mode shape and damping coefficient are usually changing very slowly when the bridge system is deteriorating in the early stage, in other words, the bridge health condition is always not sensitive with those parameters. At the same time, since a complex system include many structural parts, it has many frequency components, and they are interfered each other, so it is very difficult to use FDD to analyze a system in damage detection because it is impossible to get modal parameters exactly. Then we proposed a new method based on an overall view parameter to identify a system. In here, we assume that the system state is a dynamic variable, and a probability method with random factors was introduced as a better method to describe its present state because it is always in many random conditions (factors).

Fig. 6 shows the main principle of the proposed SRM. At first, it needs to change time domain data into the transformation domain features in the SRM. Then we are able to derive a system state variable in the feature space. Furthermore, we need to make the statistic probability distribution of the derived variable. Finally, the question of "condition assessment" of the present system becomes into a problem of "state assessment".

As stated above, among various damage detection methods, the vibration-based one is most widely used, the core idea is that vibration responses are directly relative with the physical structure and properties, such as mass, stiffness and boundary conditions, and those changes of vibration responses can be used to characterize the structural damage. Although many intuitive and considerable research efforts have been devoted on it during the past decades, assessing structural damage in large-scale bridges still remains a challenging task for civil engineers. A research [6] shows that many factors can affect the assessed results, such as the insensitive of modal properties to local damage of bridge structures, uncertainty and incompleteness in measurement data, modal variability arising from varying operational and environmental conditions, and modeling errors in the analytical model

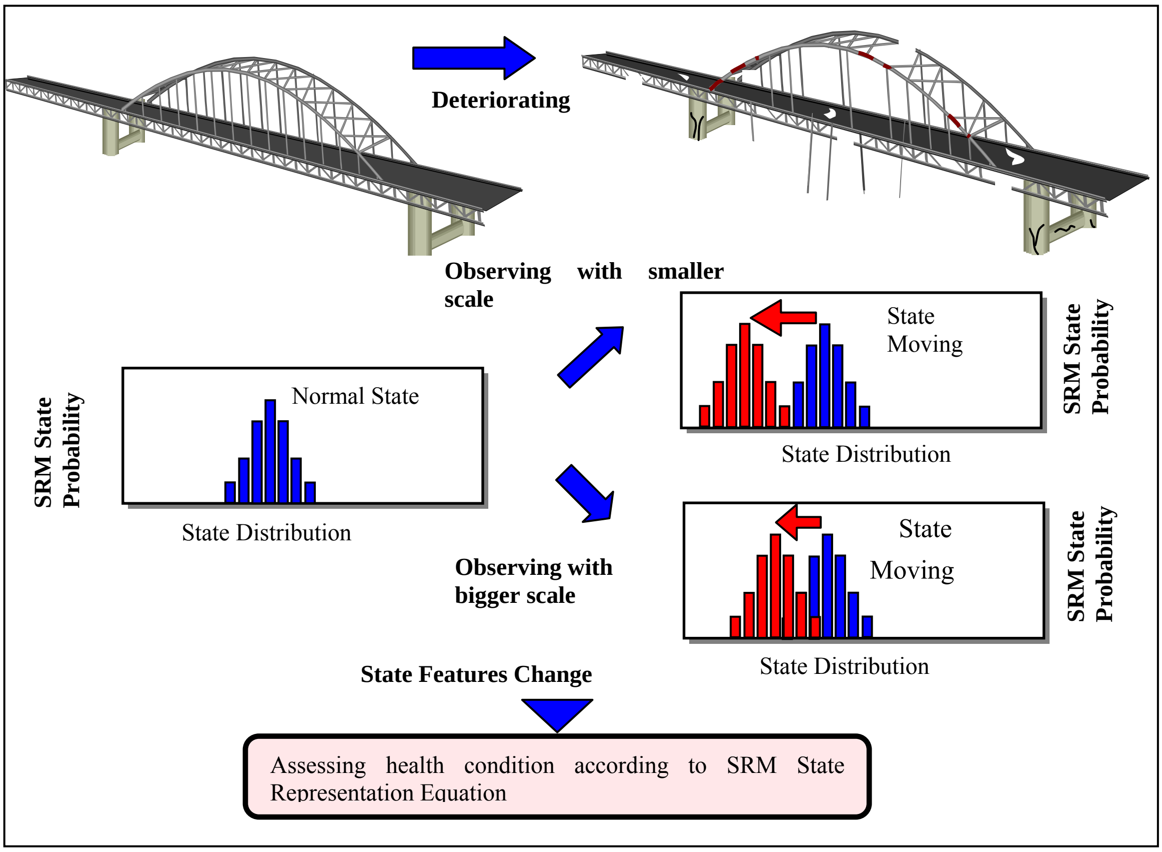


Fig. 6 SRM principle.

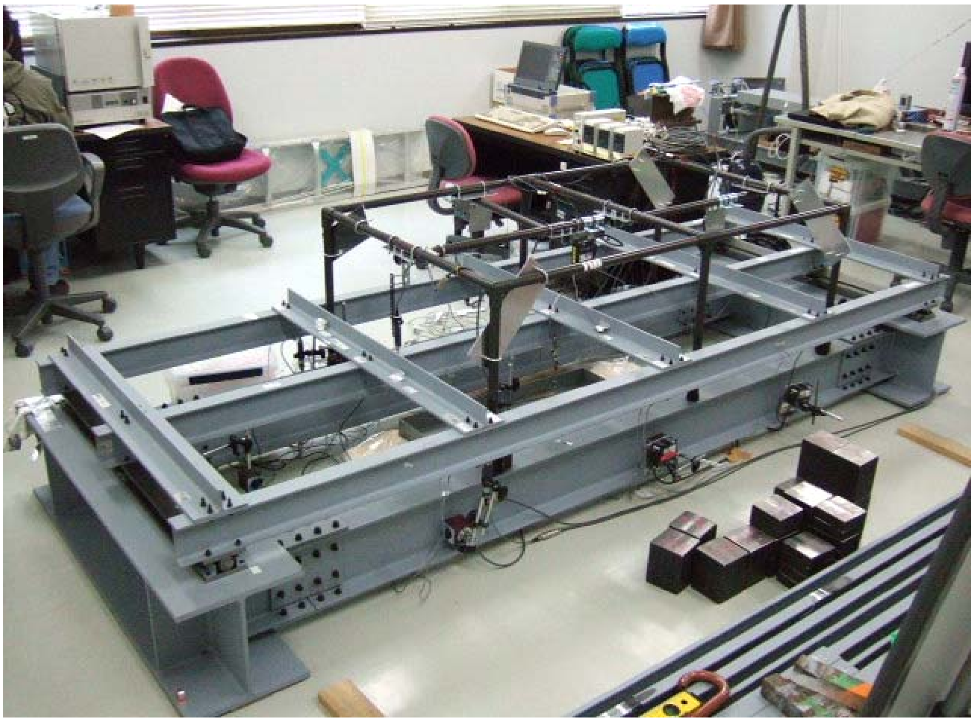
etc. Use of physics-based damage detection or model-based damage detection methods often lead to update a large number of damage parameters, especially when the structure has an abundance of structural members. Therefore they have to reduce their parameters. One problem which may arise with this method is that parameter reduction may identify the most damage-sensitive parameters but may fail to locate the damage correctly. At the same time, these same factors often lead to the ill-conditioning of model updating and damage detection problems, where small measurement noises could be magnified, this means that noise or complex factors can always corrupt the analysis accuracies. However, the sensitivity and the stability of a method are simultaneously important to the practical applicability. Meanwhile, many literatures don't consider these facts that the model updating condition is dynamic and our knowledge is an embedded process as the time ongoing. Therefore, not only requires the improving of approaches for model updating and damage detection, but also our methods should be built on a process of observation by means of continuously accumulated data. The SRM gives the method driven by monitoring data or by experience data in inspection. The SRM directly helps to know what is the difference between "virgin" state and "damaged" state after an observed time. A nonparametric structural damage detection methodology based on nonlinear system identification approaches is presented for the SHM.

3. Application to Laboratory Bridge Monitoring System

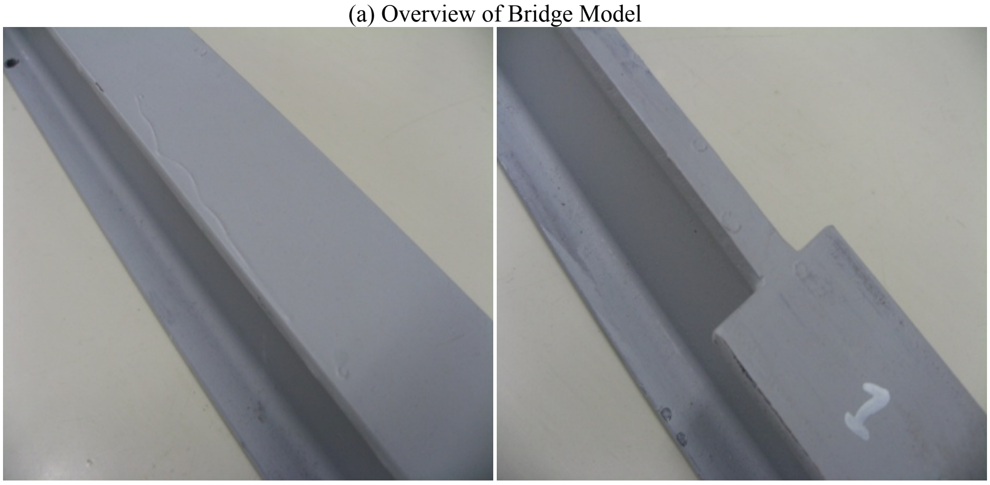
3.1 Outline of a Laboratory Monitoring System by Bridge Model

The bridge model used in this study is a simply supported girder bridge model with three main girders, which is the minimum number of girders needed to obtain necessary information such as load distribution characteristics in the direction perpendicular to the bridge axis. Fig. 7a shows the bridge model prepared for the purposes of a laboratory bridge monitoring system (LBMS). As a damage effect capable of modeling the effects of many types of damage in an idealized way, a decrease in flexural stiffness was mainly considered [7]. Girder stiffness reduction was introduced by reducing lower flange width such as Fig. 7b [no-damaged] and Fig. 7c [damaged]. A total of six damaged girders with various damage conditions were prepared for impact hummer dynamic tests. These girders were replaced with sound (no-damaged) girders to above mentioned damage conditions.

Single impact load as the dynamic test was applied to flour points (B1-D3 in Fig. 8) of the bridge model by using an impact hammer. Accelerometers were installed in bottom flange of the main girders as shown in Fig. 8 (acc1-acc9**)**. To enhance the accuracy of the transfer function, impact loads were applied 10 times at each point.



(a) Overview of Bridge Model



(b) Main girder without damage (c) Main girder with damage in lower flange

Fig. 7 Details of bridge model for laboratory bridge monitoring system.

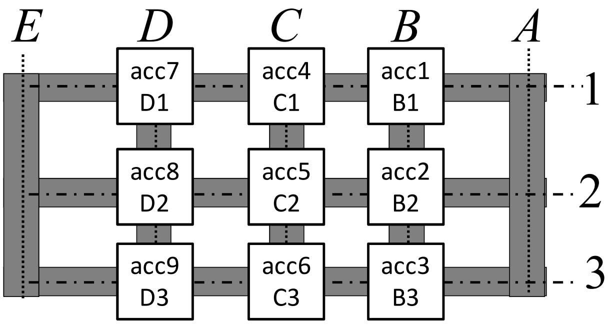


Fig. 8 Details of bridge model for laboratory bridge monitoring system.

3.2 Condition Assessment of Bridge Model Based on SRM

Fig. 9a shows an example of acceleration response of a main girder as the laboratory monitoring data. Based on the time domain data, the SRM algorithm as shown in Fig. 10 will be applied to get the state variable ζ as bridge condition assessment. In the algorithm, it is necessary that the system features need to extract from the complex responses observed data in the system. A new time-frequency analysis tool, called "Frequency Slice Wavelet Transform (FSWT)" [4] which is implemented to transform the time domain data into the time-frequency domain data will be able to powerfully reveal a change of the characteristics in vibration signal. Figs. 9b & 9c show an example of Fourier spectrum and 2D map of FSWT with feature extracting grids on an impact hummer test data, respectively.

Based on the SRM algorithm as shown in Fig. 10, we will be able to get the distribution of state variable ζ,

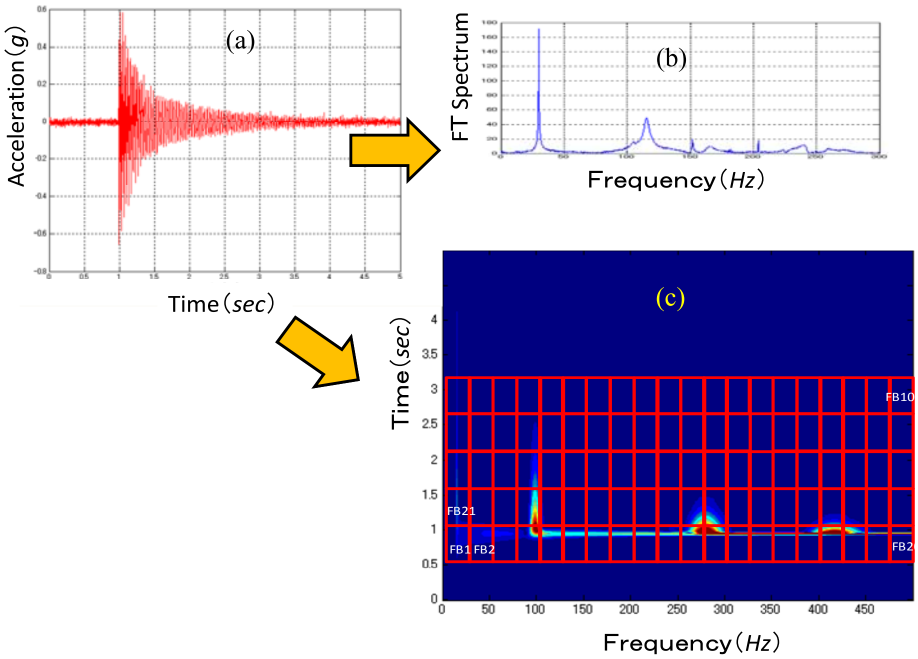


Fig. 9 SRM transform; (a) Original signal, (b) Fourier spectrum and (c) 2D map of FSWT.

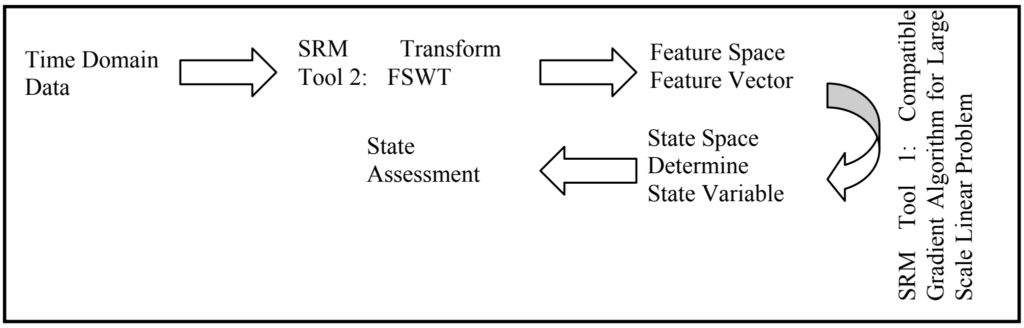


Fig. 10 SRM algorithm.

that is the state probability distribution, as shown in Figs. 11 and 12. Here, Fig. 11 shows the results of comparison between C2 damaged (symmetry state; see Fig. 8) and no-damaged girders on the SRM state probability distribution. As the same manner, Fig. 12 shows the results of comparison between C3 damaged (asymmetry state; see Fig. 8) and no-damaged girders on the SRM state probability distribution. It is clear that damages like girder stiffness reduction tend to not only move away the peak value of SRM state probability distribution from their normal (original) state (ex. $\zeta \fallingdotseq 0.0096 \rightarrow 0.0036$ for C2 damage & $\zeta \fallingdotseq 0.0096 \rightarrow 0.0048$ for C3 damage) but also change the parameters related to state variable. Then, it is found that based on these distributions, we will be able to recognize the condition changes between the current state and previous state (normal state) in a deteriorating bridge.

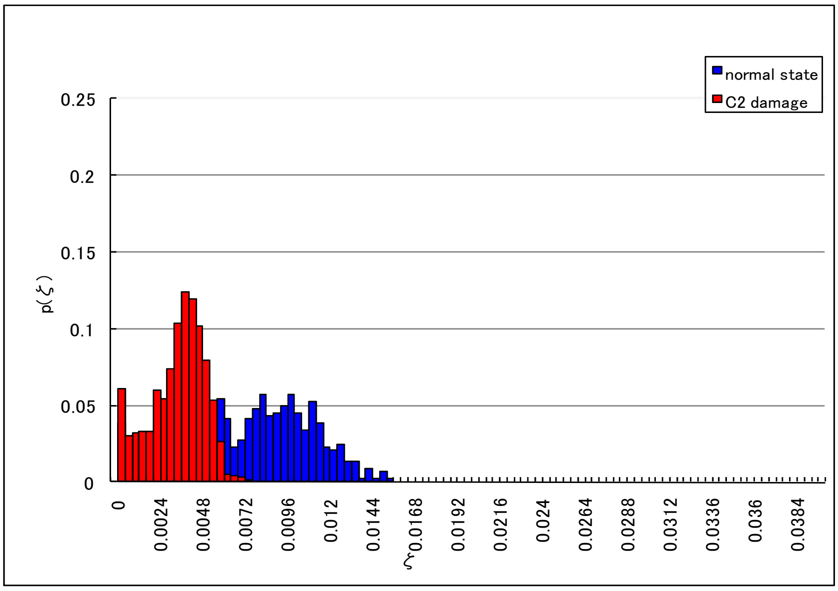


Fig. 11 Comparison between C2 damaged and no-damaged (normal) girders on SRM state probability distribution.

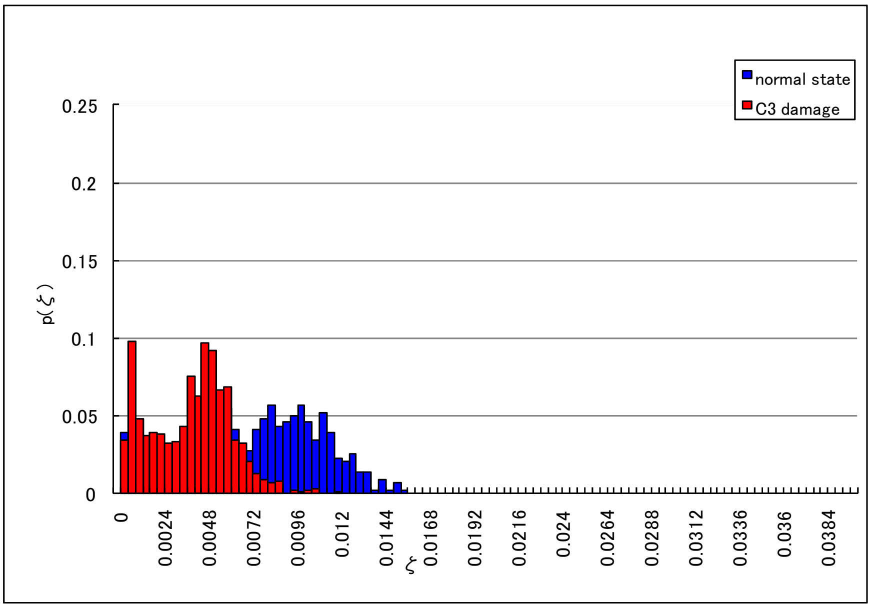


Fig. 12 Comparison between C3 damaged and no-damaged (normal) girders on SRM state probability distribution.

4. Concluding Remarks

This paper introduced the details of a newly proposed "State Representation Methodology (SRM)" and its application to bridge condition assessment based on the bridge monitoring data. The SRM is a novel tool that can provide some ideas and algorithms for data mining in the bridge monitoring system. The state of a system such as bridge structure could be obtained by a state variable ζ that calculate from a State Representation Equation (SRE). A Kernel function method which plays an important role in the Support Vector Machines (SVM) was applied to get solutions of the SRE. In the computation of the SRE, it needs to be changed into a Large-Scale Linear Constraint Problem (LSLCP). And a new time-frequency analysis tool, called Frequency Slice Wavelet Transform (FSWT), was able to powerfully reveal a change of the characteristics in vibration signal. Finally, an application example in the laboratory bridge monitoring system was presented so as to demonstrate how to apply the SRM to practical problems.

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Managing Accessibility — The Configurational Approach to the Inclusive Design of Urban Spaces

Valerio Cutini
Department of Civil Engineering, University of Pisa, Pisa, Italy

Abstract: This paper concerns the theme of the universal accessibility to urban spaces, proposing the contribution of configurational approach to their inclusive design. Born in the first Nineties on the roots of the efforts and the studies for reducing material and architectural barriers for disabled people, such discipline extends its sphere and purposes so as to mitigate the effects of spatial exclusion of a wider and wider variety of human categories, up to virtually include any potential urban user. Several questions persuade that a merely functional approach, essentially based on the position of the located activities, cannot be said satisfying: only a configurational approach can account for the effects of the grid configuration on the actual accessibility of its spaces. Our research focuses on Italian urban settlements, which appear as ideal case studies, due to the typical consistency of their urban spaces, which, especially in the inner historical cores, are densely build, geometrically irregular and hence generally far from actually providing a universal material accessibility. Here the impedance of space is much more than a theoretical hypothesis and concrete interventions are generally requested to eliminate or reduce its barriers and to make space actually and safely usable. Rather than at indicating the technical solution of single urban problems, which of course are strongly different each other, the research aims at defining a method suitable for any local context. Such method, integrating into a reliable tool the configurational vision with the functional and interactional approach, will provide a hierarchy of urban spaces with reference to the necessity of their universal accessibility.

Keywords: Accessibility, configurational analysis, inclusive design, town planning.

1. Introduction

The universal accessibility of the urban spaces is one of the themes that in the recent years has gone attracting a growing attention: the progressive ageing of the population as well as the increasing expectation of a normal fruition of buildings, spaces and functions from people of all conditions involve the pressing need of modifying spaces and paths, in order to upgrade their actual level of material accessibility. The growth of an exigency like that goes matching with the cultural development around the approach to the theme of disability and accessibility. Once, around the first 80s, such matter did actually coincide with the theme of the removal of the architectural barriers, and essentially consisted in the efforts for reducing the material obstacles that physically keep the disabled people from the actual use of the space, so as to discriminate or even to exclude them from social life and human relations. It really was a philanthropic kind of approach, and, as a matter of fact, it has gone providing remarkable results, driving the governments of several countries all over the world to issue laws and regulations aimed at imposing a minimum threshold, consisting in an acceptable level of accessibility of some categories of buildings (such as public offices, public services, restaurants and hotels). Among them, we can mention the Americans with Disabilities Act (ADA) of 1990 in the United States [1], recently modified by the Americans with Disabilities Act Amendments Act (ADAAA) of 2008, the Disability Discrimination Act of 1992 in Australia and the Disability Discrimination Act of 1995 in the United Kingdom. As time has gone by, the theme has gone growing up and modifying this kind of approach, also thanks to the overcoming of a strict interpretation of the definition of disability. As a

Corresponding author: Valerio Cutini, PhD, professor, research fields: town planning, urban modeling, spatial analysis, configurational analysis. E-mail: valerio.cutini@ing.unipi.it.

consequence, the discipline has extended its sphere and purposes from the mere protection of disabled people towards the mitigation of the effects of spatial exclusion of a wider and wider variety of human categories: we obviously still refer to disabled people, but also to elderly people, weak and sick persons (such as, for instance, heart patients and obese persons), and even to transitory invalids and occasionally impaired persons (such as injured persons and pregnant women) as well as children, up to virtually include any potential urban user; what hence provides the term accessibility with the attribute universal. The language in fact has gone underlining this aspect, substituting in the common speaking the previous terms barrier-free or disabled accessibility with other notions (substantially equivalent each other), such as inclusive design, design for all, universal design, integral accessibility. Summing all up, making a space universally accessible means to make it usable without any limitation by every kind of people, so that each person, regardless of his age, sex, social class and specific condition, can be free of any obstacle that may exist in buildings, transportation terminals, sidewalks, paths, roads and vehicles, and then normally behave and feel free from any spatial restriction and discrimination in his daily life and relations [2]. In the last decade several operators, foundations and institutions have been working on this issue, promoting cultural development, scientific researches, information, and concrete interventions on the theme.

Indeed this new kind of approach has given a stimulus to a large amount of studies on the theme, which have gone generating a wide set of architectural solutions, suitable to solve (or, at least, to acceptably mitigate) a large quantity of problems regarding the accessibility of urban and architectural space. As an example, for what specifically concerns the open urban spaces, solutions have been worked out and largely experimented for eliminating the steps in the sidewalks and in the accesses to the buildings, for easily accessing to parking and recreational areas, for safety crossing vehicular roads, for getting over differences in height, drops and slopes, for choosing the correct size and paving materials of sidewalks and pedestrian paths, and so on. A detailed treatment of such solutions, that appear irrelevant to the purposes of the present research, can easily be found in the wide specific literature (in particular see Refs. [2–7]).

If then the question regarding the technical way of enhancing the spatial accessibility can be said plainly set up, at the moment what concerns the actual realization of the interventions is instead far from an acceptable solution. The efforts so far appear in fact essentially concentrated within the most prominent public activities, and are aimed at upgrading their inner accessibility; in such sense, laws and regulations in several countries are getting more and more strict for what concerns the inner architectural space, extending instructions and duties even to private residential buildings. On the contrary, the grid of the paths which connect them and all the open spaces mostly remain an unexplored field, and its elements are still far from being regarded as universally accessible. The question, of course, is mainly an economic matter: the intervention for modifying the public open space in order to make it accessible would be extremely expensive, due to the large extension of the whole grid, to the large amount of any kind of obstacles and to the frequent presence of constraints and limitations. In Italy, these problems appear particularly difficult to face, due to the irregular orographic consistency of a large part of the urban settlements, which, often located on the steep hills, can hardly be made actually accessible. Beside, most of the Italian settlements have grown around an inner ancient core, often still enclosed within the original town walls, which is densely and irregularly build and characterized by tortuous and narrow paths: here, where most of the prominent urban activities are located, the intervention for the inclusive design of public open spaces would be very expensive and subjected to several architectural duties and limitations. Working on the theme of the physical accessibility of urban space, Italian settlements hence appear as ideal case studies, because here problems and difficulties often result so magnified as to be assumed as paradigmatic. Here the conditions of the context hinder the pedestrian movement by several kinds of material barriers and make the spatial impedance much more than a theoretical assumption or a conceptual notion; here the universal accessibility is a hard challenge to face and then an expensive target to gain.

These obvious remarks therefore lead to assume the universal accessibility of the whole urban grid as an asymptote, and hence to regard each effort for reducing exclusion and segregation as a step towards such ideal goal. Basing on the consequent evidence that the whole space of a settlement cannot be made all equally and universally accessible, a fundamental question does hence arise: which paths should be reclaimed from any possible material obstacle? In other words, the matter regards the way of selecting, within the whole grid of an urban settlement, the parts that ought to be interested by an intervention aimed at making them universally accessible. More in general, the question is the way of calibrating the actual level of physical accessibility requested by each single part of a settlement, from the lowest degree up to its highest grade, that is the universal accessibility; and this question is anything but obvious, as well as essential for avoiding to waste resources and for the optimal distribution of the available budget. In Italy, the first laws regarding the removal of architectural barriers date back to 1989, when two acts (L. nr. 13/1989 and DM nr. 236/1989) essentially imposed a minimum standard of accessibility to the inner space of new buildings. Later, a specific kind of urban plan, named PEBA (Piano per l'Eliminazione delle Barriere Architettoniche, or Plan for Architectural Barriers Elimination) was established by other acts (L. nr. 104/1992 and DPR nr. 503/1996), aimed at extending to the urban spaces an acceptable level of accessibility. Such plan was specified in several Italian regions by the local laws, and in Tuscany, one of the keenest regions on the theme of disability, a specific act was passed in 1991, imposing the PEBA to each local municipality. Nonetheless, at present the guidelines for the construction of those plans have not yet been passed, just few PEBAs have been worked out, and the presented ones appear far from being satisfying, in that they are limited at monitoring and managing the actual degree of the present material accessibility of the most used paths; when, rarely, some concrete intervention is provided, this is selected on the mere basis of a discretionary and intuitive evaluation. It’s then clear that an objective method for calibrating the need of accessibility in the urban grid is definitely advised and highly requested, in order to make actual the respect of the existing laws and to avoid the waste of the available resources. Although obvious, it's worth pointing out that an effort like this would be unnecessary if only the local conditions and the economic resources could allow to plainly extend a universal accessibility all over the grid; what unfortunately everywhere, but in particular in Italy, is still so far from happening.

2. The Methodological Approach

The easiest and most frequent approach to the question is functional: since the most prominent public activities ought to be located in accessible buildings, also the paths that connect them (at least the shortest ones or, even better, the most used and then crowded) should hence be made universally accessible. Several faults are hidden behind this apparent solution. First, which activities along the paths of the grid such accessible paths should connect? Beside, activities can be easily and frequently moved or displaced: what then about the effects of their possible shifting on the accessibility of the connecting paths? And, if we assume to preferably connect the most relevant punctual activities, what about the diffused ones (for instance shops, offices and minute services), that are atomized and capillarity scattered along the paths of the urban grid? And, finally, what about the residential function, which in most cases appears homogeneously distributed all over the settlement and does generate a large amount of the origin destination movements to all the other activities? All these questions are hard to answer, and make hence evident that a merely functional approach, essentially based on the presence and the position of the located activities, cannot be said satisfying, since it cannot reliably identify the most used and crowded paths in order to assure them a universal accessibility. In other words, and more in general, the grid of the urban paths cannot be seen as the mere inactive stage where activities mutually interact; space does matter, in that its configuration affects the way the space itself is actually used. This remark induces to set aside the located activities and to focus on the urban grid, to be seen as a "machine for maximizing contacts" and interactions [8]; the analysis of its configuration will then be expected to provide significant results with reference to the likely use of the urban space. Such results could possibly be integrated with the results of a traditional interactional analysis, based on the functional consistency of the settlement: the urban grid with its configuration in a one hand and, in the other hand, the activities with their position and their consistency will then allow a calibration of the relevance of the paths with reference to their actual use and hence the opportunity of assuring them an acceptable level of material accessibility.

In the last decade, a remarkable amount of researches have been applied to test the actual reliability of the configurational approach. Studies [9] did verify the existence of a narrow correspondence between the configurational indices (in particular the integration value) with the pedestrian movement rates; further studies [10] did then verify also a strong correlation of the same configurational parameters with the actual presence of the located activities. As a matter of fact, these researches and others have proved the techniques of configurational analysis as a reliable tool for reproducing the distribution of the attractiveness towards the activities, and hence the distribution in a whole urban settlement of the level of centrality, if we define it in terms of appeal for the location of activities. Summing all up, on such basis we may assert the integration value as an indicator of the pure accessibility, meaning by the attribute pure the independence of its value from the presence and the position of the located activities. In other words, the integration value represents in the configurational vision what the economic-spatial potential is in the interactional approach. The economic-spatial potential of a location *a* is analytically described by expressions like the following ones:

$$Ea = K\Sigma j\ \omega j\ daj^{-\gamma}$$

or

$$Ea = \Sigma j^{\alpha}\ \exp(-\beta caj)$$

respectively according to a traditional gravitational approach [11, 12] or to an entropic vision [13], where ω_j is the size of the j activity, d_{aj} its distance from the location and c_{aj} the respective movement cost. The economic-spatial potential is also commonly called generalised accessibility, since this kind of accessibility is here computed on the basis of the activities which are actually present, without the external and axiomatic assumption of a centre, traditionally defined [14] as the most desirable location for any kind of activity. Therefore it appears clear that the generalised accessibility (i.e., the economic-spatial potential) and the pure accessibility (i.e., the integration value) respectively represent in the interactional approach and in the configurational one the specific indicator of the relevance of each part of a settlement as an attractor (of movements and activities). It is singular (and significant) the apparent recurrence, with different meanings, of the notion of accessibility: defined in classic modeling as the opposite of the spatial impedance in the relations between activities, and then depending on their distribution (generalized accessibility), assumed in the configurational vision as determined by the configuration of the urban grid (pure accessibility) [15], appraised in the inclusive design as the possibility of using the space without any limitations (universal accessibility). Linking all up, the idea at the base of this research may be summarized saying that the distribution of both pure accessibility and generalised accessibility, integrated and taken together, can usefully indicate for each part of a settlement the specific opportunity of providing it with a material universal accessibility.

3. Our Case Study

Pisa has been selected as our specific case study, in order to apply a configurational approach to support and guide the construction of a PEBA. Several particular features concur in making Pisa an excellent urban laboratory for this kind of test. First, the size of the settlement: Pisa has got a population of around 100,000 inhabitants, what make it big enough for the significance of the results, and small enough for exhausting the analysis and complete the processing of the method. Second, the presence of a large (when compared to the extension of the whole settlement) historic core, whose origins date back to the XIII century and is at present still substantially unchanged; though a large part of the most prominent activities is still within this core, yet its geometric and morphological features make of course buildings and open spaces full up with obstacles and then hardly accessible. Besides, the presence of an enormous (again, comparatively) University: side by side with the local inhabitants, more than 50,000 students and about 2,000 teachers and researchers live in Pisa, giving life to an articulated network of interactions and movements to the University sites, which of course ought to be made easily accessible to anybody; a large amount of strong attractors does hence characterize the settlement. Finally, the presence of some highly relevant tourist points of interest, and among them mainly the leaning tower and its monumental adjacencies: millions visitors are annually attracted here from all over the world, and of course also this mighty attractor ought to be made universally accessible.

With this purpose, we have focused on the present urban grid of Pisa, as it can be drawn out of the CTR (Carta Tecnica Regionale, the 1:2,000 planimetric base representation of the regional territory provided by the Tuscan regional administration) setting aside any other material object except the mere perimeter of the public spaces, that is those which can be used without any limit by everyone. The urban grid was then processed by Depthmap software, submitting its axial map, consisting of around 1200 lines, to axial analysis. Such processing did provide as a result a complete representation of the distribution of the configurational indices in the lines of the axial map, and, what's most relevant for our purposes, the distribution of the integration value all over the grid. As we have seen above, in fact, integration reproduces the distribution of the levels of attractiveness towards activities, and hence the distribution of centrality within an urban settlement. The distribution of global integration in the lines of Pisa, as it results from Depthmap processing, is here shown in Fig. 1.

Furthermore, the same analysis provided the distribution of local integration (that is radius 3 integration) in the lines of the grid of Pisa. Of course, those two analyses actually provided far different results: the representation of global integration, in fact, shows an evident centripetal distribution, with the strongest integrators materialized by the prevalent north-south axis, correspondent to the streets Borgo Stretto and Corso Italia, and in several orthogonal streets. These, as well as several less important streets which surround them, materialize the present integration core of the whole settlement, which is here represented in Fig. 5. A completely different layout arises from the representation of the distribution of radius 3 integration, presented in Fig. 2: here several strong local integrator appear, variously scattered in the urban grid from its inner core up to the far edge of the settlement; on the contrary, the lines resulting main global integrators in Fig. 1 still maintain high values of radius 3 integration in Fig. 2 and hence their strength as main local integrators.

With reference to the theme of centrality and hence

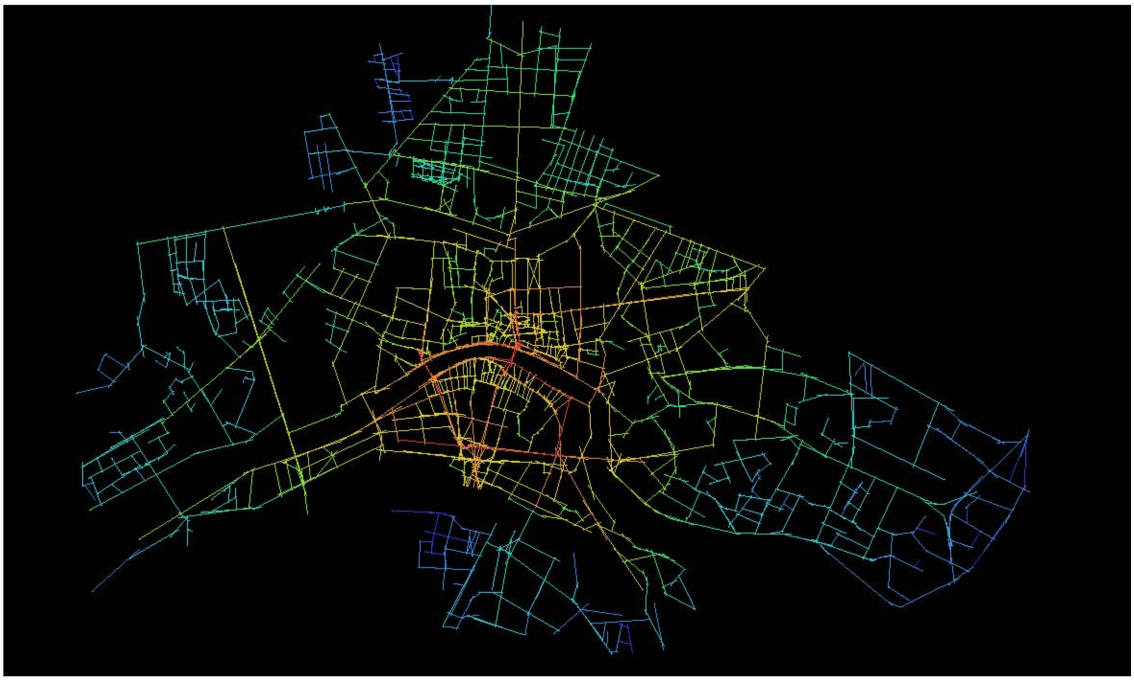

Fig. 1 Chromatic representation of the distribution of global (R = n) integration in the urban grid of Pisa.

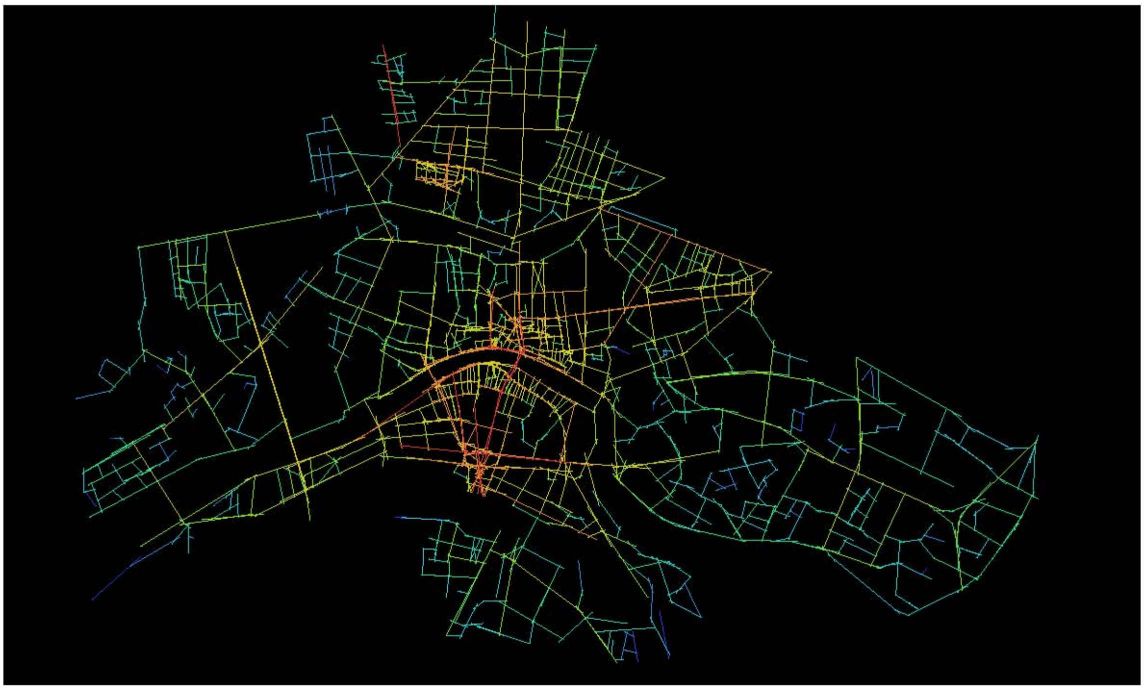

Fig. 2 Chromatic representation of the distribution of local (R = 3) integration in the urban grid of Pisa.

to the functional pattern of the settlement, the researches so far allow to interpret such a radical discordance and the different significance of global and local configurational values: the global integration, as we have exposed above, was proved [16] able to describe the level of centrality of each part of a small size settlement; all the same, if we analyze the whole urban area of a bigger settlement, we may notice that correlation of activities versus global integrations does weaken, while, within limited infra-urban areas, we observe a narrow correlation of the same activities versus the local integration value. In Pisa, we have selected 120 lines and we have observed the activities actually located in the correspondent streets; the results of the analysis of the correspondence of radius 3 integration and density of activities shows that a strong correlation connect them within local sub-systems; assuming each of them as defined by the lines gravitating towards a strong local integrator, in Pisa we have identified 10 sub-system, and then we have analyzed 10 different (but analogue) correlations. In other words, the observed correlations seems to reproduce the presence of several sub-systems of the grid; the correlation of activities versus local integration, that weakens if extended beyond each sub-system, is on its turn strongly influenced by the distribution of global integration. Summing all up, we may observe that in each sub-system the local integration value IR3 and the density of activities A appear narrowly correlated according to the following expression

$$A = K \exp W\, IR_3$$

where the coefficients K and W stands for the effects of the global centrality (due to several elements: among them, the global integration value, the presence of strong global attractors, the demographic density of the area and the presence of relevant utilities and amenities) of the integrator of the sub-system on that correlation. As a consequence, the expression above can be represented by mean of several exponential curves, and each of those curves is referred to the correspondent sub-system, around its own local integrator. Other conditions being equal, the higher is the global integration value of that integrator, the higher in the (IR3, A) graph we will find the correspondent curve. Roughly speaking, a clear layout can most likely account for this correspondence: an urban settlements characterized by several local centres, with different levels of global relevance, and hence of global attractiveness; and within the area surrounding each of them, a narrow correlation between radius 3 integration and attractiveness, as materialized by the present density of activities. In such view, different kinds of activities are likely to populate the different level centres: common activities (that is activities which are not worth long distance movements, such as retail shops) mainly directed to the "peripheral" centres, rare activities (that is addressed to a wider market area and characterized by a wider range) mainly centre oriented, that's to say strongly attracted by to the "central" centre. In Fig. 3, we may observe the representation of the exponential curves local integration versus activities in the defined subsystems, where each of them is identified by a specific colour.

It can also be argued that pedestrian movements, as mainly short and exhausting within small distances, take place in a local urban context and then are more narrowly described in their distribution by the radius 3 integration rather than by the global one. Down to the matter of this research, and if we assume the location of activities as influenced by the distribution of natural movement and producing an attracted one, it's evident that the efforts for reducing any material obstacle and for providing the public open spaces with a universal accessibility ought to be oriented towards the most attracting urban areas, as the most likely to generate and receive to and from movement from all over the grid. And such purpose should be pursued assuring accessibility both to the global integration core of the urban settlement and to the local ones.

The obvious limit of this approach is the presence of non-configurational activities, which are activities that do not necessarily follow the configurational pattern of the grid. Among them, by far the most frequent and relevant are the monopolistic activities, in that those activities can be located setting aside the distribution of the configurational parameters, since they won't suffer any damage in case of a non-appealing location [17]. Many kinds of activities share this enviable feature: among them, all the public services (schools, universities, hospitals, administrative offices), but also the public amenities (parks, museums, monuments and

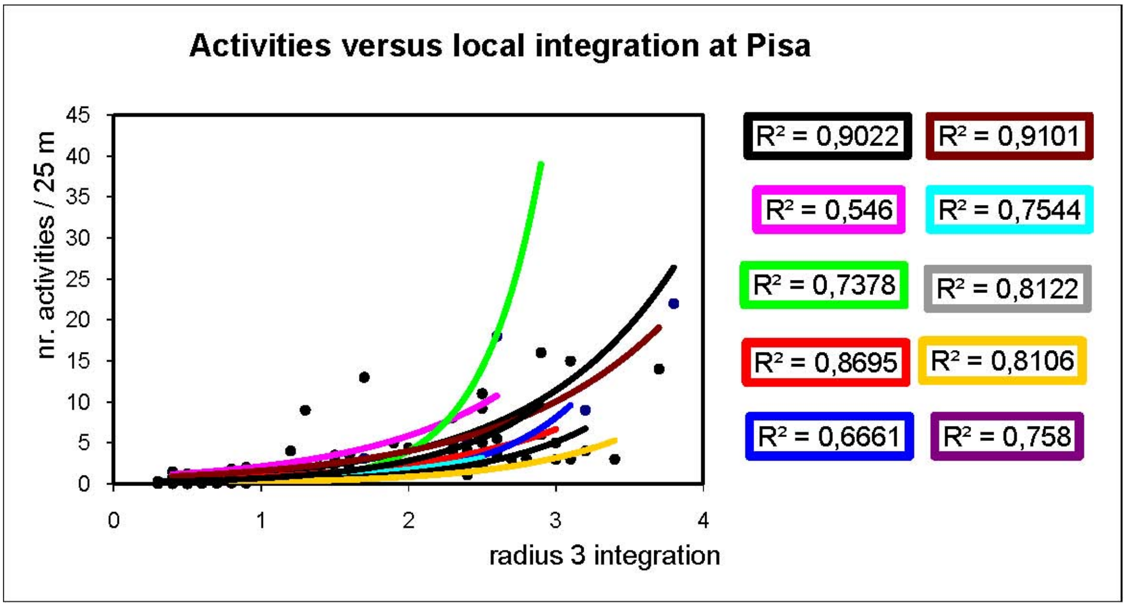

Fig. 3 Correlation of local (R=3) integration value versus density of activities in the lines of Pisa. Each colour distinguish one of the sub-systems.

tourist attractions). And just schools, universities, hospitals, administrative offices, museums and monuments are precisely what the town of Pisa is mainly made of. As a provement, we may get a look at the correlation integration versus activities mentioned above, and notice a clear lack of correspondence in the subsystem nr. 2 (where R^2 = 0.546), due to values of density of activities largely higher than the expectancy resulting on the basis of integration values. As a matter of fact, that area is characterized by the presence of several faculties (Engineering, Chemistry, Pharmacy, Medicine, Foreign Languages, Informatics: on the whole more than 25,000 students) of the University of Pisa, by the presence of an important regional hospital, the Santa Chiara University Hospital, by the presence of relevant military (paratroopers) barracks, and, above all, by the presence of the leaning tower and of the other monuments of the Piazza dei Miracoli (around 2,500,000 visitors in a year). All these activities, undoubtedly monopolistic as lacking in competitors in a wide area around Pisa, of course attract here a large amount of movement and activities (mainly hotels, restaurants, souvenirs shops, bookshops, stationery stores, etc.) although the lines of the area do actually result characterized by poor values of global integration. This obvious evidence do persuade that a PEBA merely oriented onto the configurational pattern of the grid would inevitably disregard the presence of the monopolistic activities, and more in general of the non-configurational ones; what in Pisa should clearly be dramatically wrong and unacceptable, for two main reasons: first, those activities are a large and prominent part of the urban functional structure; moreover the universal accessibility to those activities, mainly to be regarded as public and social services, is strongly requested as a necessary requirement.

It is then clear that the results of the analysis above, worked out by means of configurational techniques, ought to be integrated by a further kind of analysis, based on a functional approach, which is assuming as an input the presence, the size and the specific position of the located activities. More in detail, we decided to integrate the results of configurational analysis, and in particular the distribution of the pure accessibility index, with the outputs of an interactional model, providing the distribution of generalized accessibility; pure accessibility and generalized one, taken together, will then been assumed as a reliable indicator of the crowding of paths and of the consequent necessity of their universal accessibility. On such basis, we have assumed as our input the distribution of economic activities in the municipality of Pisa, as in Italy it is provided with a ten-yearly frequency by ISTAT (Istituto Nazionale di Statistica); we have used the data of 2001 (the most recent available data), and the selected values are expressed in the number of occupied employers and spatially referred to the singles census tracts. The whole municipality of Pisa is covered by 918 census tracts, and that partition is sufficiently minute so as to allow a systemic analysis of the settlement by means of a gravitational model. On the basis of the employments data in the census tracts, we have then calculated the distribution of spatial economic potential (the generalized accessibility mentioned above) according to the usual expression

$$Ea = K\Sigma j \ \omega j \ daj^{-\gamma}$$

what obviously implies the processing of a 918×918 symmetric matrix. We have then organized the results of the processed model by means of a GIS, using as cells the same 918 ISTAT census tracts, thus obtaining and presenting by a chromatic representation the distribution of generalized accessibility in the whole area of the municipality of Pisa, which is here shown in Fig. 4.

The several and strong differences with regard to the distribution of integration (pure accessibility, as we did assert) can be observed by the comparison of Fig. 1 and Fig. 4. The same differences may be easily noticed by the comparison of the spatial economic core with the integration core deducted by the analysis above. In Figs. 5–6, it's possible to respectively observe the global integration core and the local integration core of Pisa, while in Fig. 7 is planimetrically represented the economic spatial potential of the settlement; in all the mentioned cases, the marked out areas result characterized by values over 90th percentile.

More in detail, we may notice that high values of generalized accessibility (red cells) characterize the areas along the river Arno, as well as the whole north-west area of Pisa, where we find Piazza dei Miracoli, the Santa Chiara Hospital, the faculties of Engineering, Medicine and Pharmacy; as it can be easily understood, and could be easily predicted, such high values depend on the presence of those prominent activities, and are in contrast with the poor values of integration. On the other hand, all the main global integrators result located within high potential areas, demonstrating that a favourable position on the grid (from a configurational point of view) actually attracts activities and makes the correspondent spatial potential to increase. It's also worth saying that in the processed model we could not take in sufficient account the role of movement attractors of several activities and public services, which result provided with a limited number of employers with respect to their actual importance and attractiveness: here we obviously refer to the monuments of Piazza dei Miracoli, but also to the other churches and monuments of Pisa, as well as to the railway station and to the bus station. Therefore, in all those cases we must consider underestimated the respective spatial potential. At last, also in the interactional approach, as we did above in the configurational method, we have selected and pointed out an accessibility core, which was assumed as characterized by the areas over the 90th percentile of the spatial potential value.

The two different pattern of accessibility can therefore be integrated, so as to point out the urban spaces that, either in a configurational vision or in an interactional approach, result deserving interventions for providing a universal accessibility. The result is a grid of paths, extending from the inner core (where they are, as predictable, far denser) up the edge of the urban settlement, connecting both the configurational sub-centres and the most prominent and attracting located activities.

Obviously, a procedure like that can be regarded as too rough, in that it assumes a strictly binary logic, simply dividing all the urban spaces in two categories and distinguishing them in universally accessible spaces and inaccessible one. A slightly more detailed procedure could instead graduate the several levels of

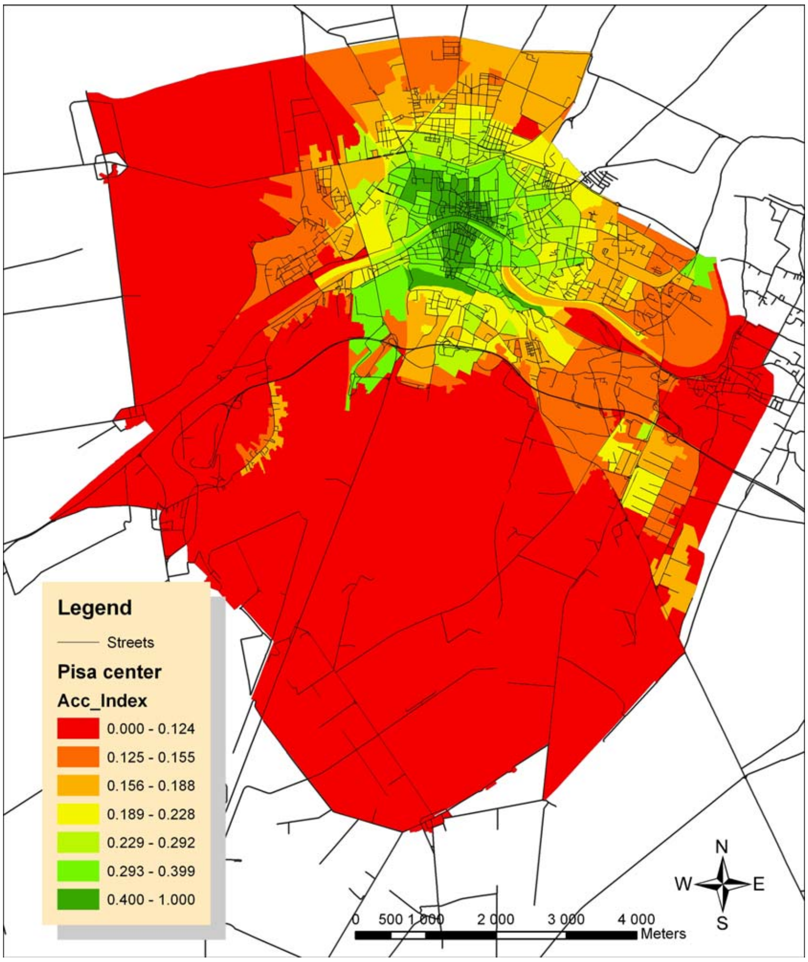

Fig. 4 Chromatic representation of the distribution of economic spatial potential in the whole area of the municipality of Pisa.

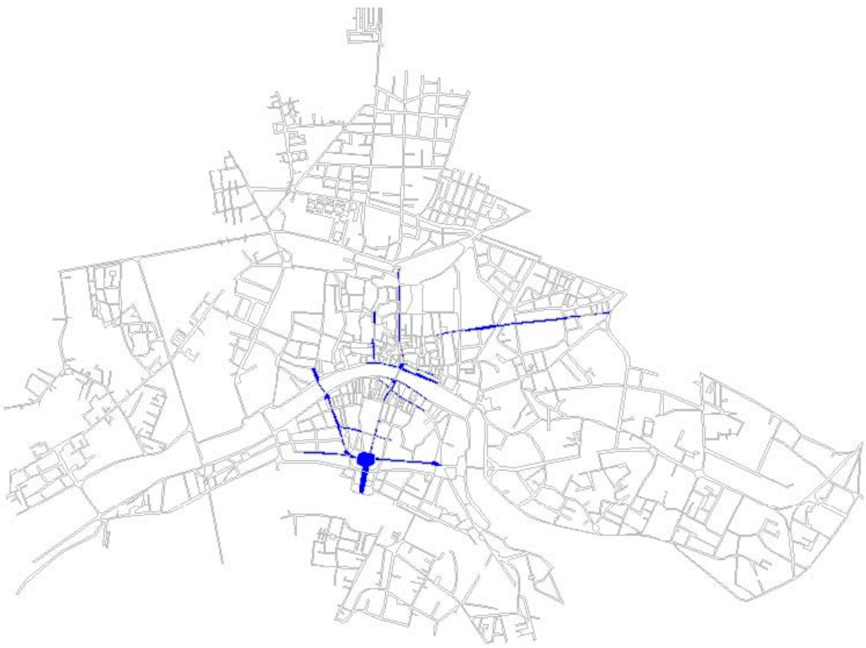

Fig. 5 Global integration core of Pisa.

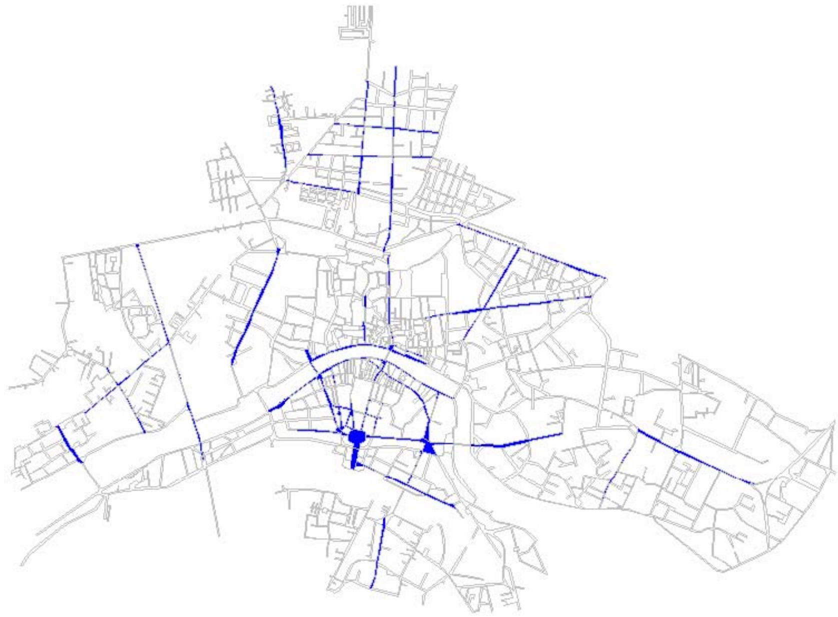

Fig. 6 Local (radius 3) integration core of Pisa.

Fig. 7 Economic spatial potential core of Pisa.

material accessibility the urban paths ought to comply with, according to their respective actual configurational/interactional accessibility. As an example, we could define three levels of spatial accessibility requirement, which could respectively be named "universal accessibility requested", "partial accessibility requested" and "accessibility non requested"; here the expression "partial accessibility" could refer to the mere elimination of the architectural obstacles and barriers, so as to just allow disabled people to safety move along the sidewalks (Gallagher, Scott, 1996). In Fig. 8 we can notice the represented result of a subdivision like that in the planimetric layout of Pisa, where the universal accessibility is requested for the paths with an accessibility value over the 90th percentile and the partial accessibility is

Fig. 8 Proposed classification of the public open spaces of Pisa with reference to the required material accessibility: in blue the universal accessible spaces, in light blue the partial accessible ones.

requested for the lines with an accessibility value from the 50th up to the 90th percentile; in the exposed representation, the universal accessibility is required for the areas which result marked in blue, while the only partial accessibility is required for those marked in light blue. Obviously, the proposed subdivision and the correspondent values are here presented as a mere example, since they can largely vary according to the specific features of the local context (that is the actual presence of obstacles or territorial impediments), to the available funds for the intervention as well as to the political willingness to approach the asymptote of the universal accessibility.

4. Conclusions

The configurational approach to the analysis of urban spaces is here applied to support the working out of accessibility plans in order to provide urban planning with an objective decision making support tool as well as to overcome the faults and the limits of the traditional functional vision. Only a configurational approach, in fact, can account for the effects of the grid on the distribution of accessibility, and hence on the distribution of pedestrian movement flows. In such sense, the experimentation of the configurational techniques to the urban case of Pisa, for several reasons here presented as an ideal case study, has provided outstanding results, as it allows to single out a widespread network of paths that, due to their centrality, are likely to get crowded with pedestrian movement and then chiefly needy of intervention for enhancing their material accessibility.

At the same time, those techniques make some physiological limits of the configurational approach to emerge, in that it can't account for the effects on movement of the non-configurational activities, and mainly, among them, of the monopolistic ones, which in Pisa are numerous, conspicuous and strongly attractive; it hence makes clear that the configurational techniques can be suitably integrated by a gravitational model, based on the interaction relations expected to connect all the located activities. The results of the configurational analysis, that is the distribution of pure accessibility (local and global integration values), and the results of the processing of a spatial interaction model, that is the distribution of generalized accessibility (economic spatial potential), taken together, indicate the distribution of the actual demand for the material accessibility of the urban spaces. Furthermore, beyond the limits of the matter of the inclusive design of urban spaces, two general results of this research appear worth noticing. First, the concrete application of the configurational techniques as a decision making support tool in the operational urban planning. Second, the integration of the configurational techniques with the traditional interactional analysis, so as to account for the effects of both grid and activities on urban phenomena.

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The Kitchen: An Architectural Mirror of Everyday Life and Societal Development

Claus Bech-Danielsen

Danish Building Research Institute, Aalborg University, Denmark

Abstract: This paper is part of a research project that analyses trends in housing architecture over the past 100 years. The research aims toshow how changing norms and new forms of everyday life have altered our views on housing and have led to fundamental changes in housing architecture. In this paper the analysis focuses particularly on the kitchen. A hundred years ago the kitchen of the bourgeoisie and the middleclass was only used by servants and other employees. Accordingly, the design of the kitchen was not a task for architects at all. However, during the 20th century the kitchen became an important architectural focal point. In the early part of the century architects considered it a practical workspaceto beimproved through rational analysis. Later on the kitchen was seen as a space with great social qualities, and the informal character of the kitchen was developed and exported to the rest of the dwelling. Today the kitchen has become the central space in many dwellings, but as the dwelling is increasingly being rendered representative value, modern kitchens are designed with emphasis on their aesthetic appearance. They are “life-style kitchens”, which demonstrate the “good taste” of the residents and reflect their personalities.

Key words: Kitchen design, housing architecture, cultural trends.

1. Introduction

This paper is part of a research project that surveys a series of momentous changes in residential architecture in the last 100 years. This was done by focusing on a number of specific functions of the dwelling, specifically the kitchen. How did the actual work in the kitchen and the view of kitchenwork change throughout the 20th century and how did this affect the spatial organization of the dwelling and the practical design of kitchens?

Primary focus is on developments in Danish housing. However, international developments have also been included, if they have been important for changes in Denmark. This means that the relationship between international developments and Danish developments varies in the description of the various periods. In particular during the period 1920–1930, change was primarily on the international stage rather than in Denmark, but in the post-war period, focus turned to concentrate on developments in the kitchen in Denmark, so this section focuses more on Danish conditions.

The method included literature studies. On the one hand these studies focused on societal and cultural trends (health, hygiene, rationality, food culture, gender, sustainability, consumerism etc.) and on the other hand they focused on housing architecture, changing residential conditions as well as kitchen design. A number of typical house plans of the periods have also been analyzed. These analyses primarily focused on the spatial conditions of kitchens — the size, the location and the design of kitchens. The emergence of conditions typical of each individual period was often discovered through comparison across the different periods.

This paper presents some results of the study. It will be shown how kitchen design and its relation to everyday life in the dwelling has changed over time. With focus on the kitchen, it is shown that housing architecture has undergone drastic changes over the

Corresponding author: Claus Bech-Danielsen, PhD, professor, research field: housing architecture. E-mail: cbd@sbi.dk.

last 100 years. Thus it becomes obvious that the concept of “good housing” has constantly been changing. We may imagine that housing today will meet future housing needs, but in the light of the previous changes, we have to recognize, that the future is also likely to bring great changes.

2. Once Upon A Time — Kitchens 100 Years Ago

In the early 1900s it was rare to find a woman from the middle class or the bourgeoisie in her kitchen. The American housing researcher Sudjic compares contemporary kitchens with the engine room of a ferry: it was a workspace for the crew and a place where passengers were unwelcome [15]. The kitchen was the domain of the servants, and the role of the housewife in relation to work in the kitchen was that of an employer [4, 15]. Her only contact with the staff was when the cook or the housekeeper went upstairs to the living rooms in order to discuss the menu for the day.

Thus, at this time having a nice kitchen was not associated with status. Cooking was associated with hard and dirty work: firewood was carried, meals were prepared from scratch, smoke and dust came from the cooking range etc., and the status related to the kitchen was usually based on the number of servants employed [3]. The servants’ work in the kitchen was not meant to be seen, heard or smelled in the rest of the dwelling. Neither guests nor masters were supposed to concern themselves with the work in the kitchen, and they met the servants as less as possible.

In contemporary housing the kitchen was therefore located far from the primary spaces of the dwelling. In this context it should be remembered that contemporary housing had a strong representative character. In villas the kitchen was typically located in the basement, next to laundry, coke depot, servants’ rooms, etc., and in multi-storey buildings the kitchens were located in the “private section” of the dwelling - and always oriented towards the backyard (see Fig. 1). The advantage was that noise, smoke and smell did not spread to the representative part of the house, but at the same time it meant that the kitchen was located far from the dining room. This was inconvenient for the workflow around cooking and serving, but quite logical in a period where the comfort of the gentry took priority over convenient working conditions for the servants.

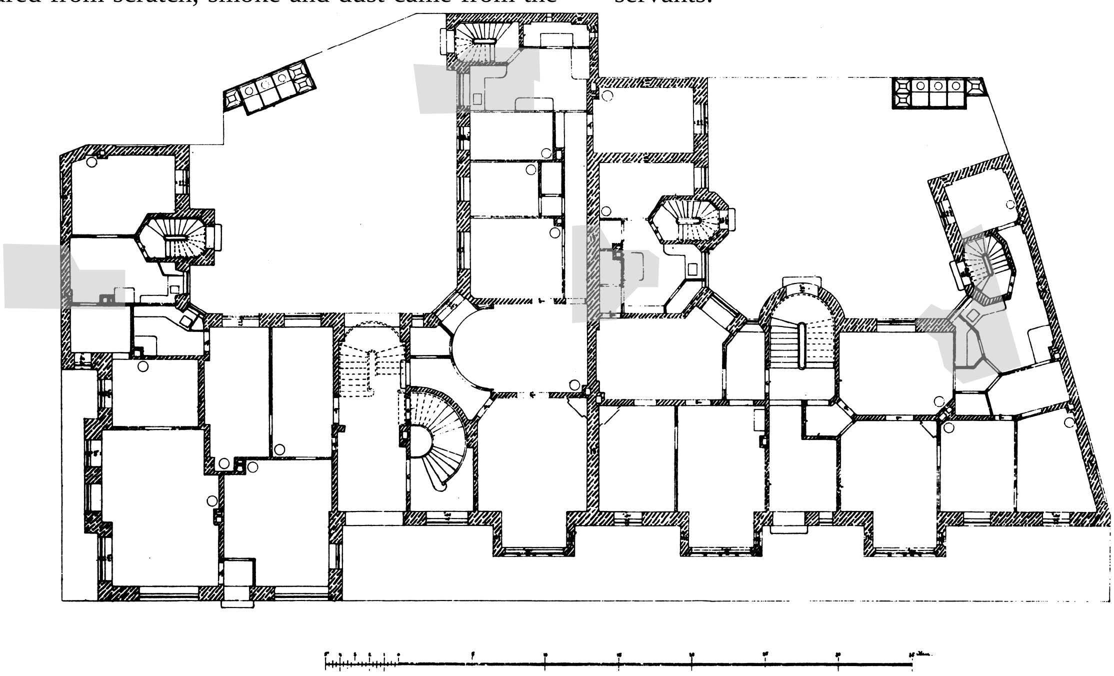

Fig. 1 Danish Housing from 1898: The kitchens are oriented towards the backyard, they have scattered furnishing and no coherent layout.

There was ample space in the houses of prosperous citizens, and kitchens were also relatively spacious. They served as both work and dining areas for the staff [18], and a table was usually placed in the middle of the kitchen around which employees could eat their meals. A number of rooms were related to the kitchen: a cool pantry for storing food was a necessary part of contemporary kitchens and in the large residences there was even a pantry where the food was arranged before being carried into the dining room.

Since kitchens were spacious, since it was easy to find cheap domestic servants, and since no one was interested in the working conditions of servants, no one focused on the kitchen as an important workplace. Kitchen layout was dictated by other factors [14]. For instance the position of the chimney dictated the position of the stove, and as the chimney was supposed to double as a heat source and exhaust duct for more than one room, the chimney was usually located well inside the house and away from the windows. Of course this made it difficult to ventilate the kitchen for smoke and heat. The sink, on the contrary, hung on the wall facing the backyard, as the wastewater was drained directly into the courtyard (until a sewerage system was implemented).

Usually there were many doorways in a kitchen. One door served as the entrance to the kitchen — typically from a corridor, another door led to a pantry, and often other doors would lead to a storage area and a staircase. The many doorways made it difficult to establish a coherent layout for the kitchen and scattered furnishing was emphasized by the fact that kitchen components were still not arranged to form a cohesive whole in an overall design [14]. The stove was one single element, the kitchen sink hung by itself, and each piece of furniture for storage might be located in different places, and was not designed specifically for the particular space.

3. Modernism and Kitchen Design in the 1920s and 1930s

When modernists in the 1920s and 1930s developed modernistic architecture, not only housing for the wealthy was on the agenda. The architects of modernism would develop housing for the general population, and since the general population had no servants, the kitchen became an architectural topic and a significant new venture for architects. Previously architects had dealt with monumental buildings and palaces for the upper class, and as kitchen work had never been a part of their daily lives, kitchen design had never been on the architectural agenda. Thus the task was entirely new.

The architects of modernism were inspired by engineers who developed new types of products: cars, airplanes, bridges, ocean liners, etc. Engineers had their rational way of working and, as they were more familiar with new materials and mechanical production methods, they had taken the lead in designing these new products. Modernists based their design of new homes on similar rational considerations, and in so doing the kitchen was an obvious place to focus. Specific functions were performed in the kitchen, and the kitchen was therefore the perfect place to realize the concept of modernism. It was an ideal place to demonstrate rational methods and functional analysis to streamline the workflow and optimize use of space.

The trend had already been developed for some time. Christine Frederick [5], who was an American co-editor of Ladies Home Journal, made herself the protagonist of the work, and in 1919 she published the book “Household Engineering: Scientific Management in the Home” [14]. As the book’s title suggests, Frederick found her model in Taylorism, which had great success in rationalizing industrial enterprises. Frederick considered the kitchen as a company with only one employee [12, 14], and as a parallel to the rationalization experts of the factories, she identified the workflow in the kitchen in order to save time (see Fig. 2). She created an alternative kitchen: An efficient and time-saving kitchen meant only for cooking and with direct access to the dining area [5, 12]. However, Frederick’s kitchen still consisted of separate elements that were not pieced together into an overall design.

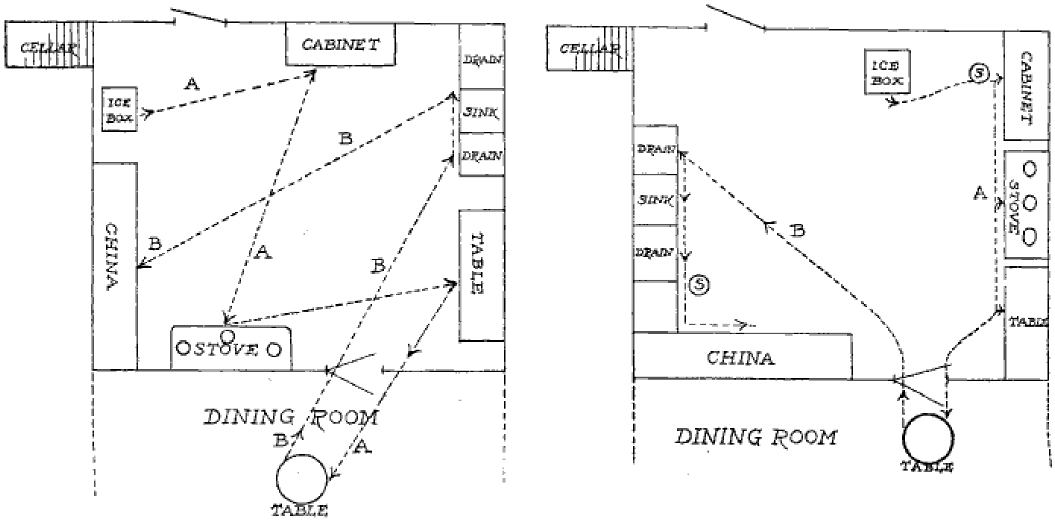

Diagram showing badly arranged equipment, which makes confused intersecting chains of steps, in either preparing or clearing away a meal. (A — preparing; B — clearing)

Diagram showing proper arrangement of equipment, which makes a simple chain of steps, in either preparing or clearing away a meal. (A — preparing; B — clearing)

Fig. 2 On good and bad examples of floor plans, Christine Frederick [5] demonstrated how cooking could be implemented by time and step-saving devices.

The ambition to rationalize and streamline work in the kitchen had its base in a society where it was becoming ever more difficult for the middle class to hire servants [14]. Around the First World War, many women found work in factories where they earned more money and experienced independence. This left the middle-class kitchens without servants. Middle-class women had no experience of kitchen work, and therefore new tools and facilities were more than welcome.

Christine Frederick's book became almost a bible for architects at the Bauhaus working on developing a modern kitchen. At the first exhibition at Bauhaus in 1923, the German architect Adolf Meyer (1881–1929) presented a design of a modern kitchen. As Frederick had prescribed, the kitchen was rationally organized, and in line with Bauhaus' standardization efforts and vision of mass production, it was even conceived as units of elements with a continuous aesthetic expression.

Another important effort of modernism also became visible in Adolf Meyer's kitchen. The hygienic movement had enormous significance for the development of modernistic architecture [1, 10], and this topic was obvious in the field of kitchen design. Thus, Meyer's kitchen from 1923 had bright and shiny surfaces that could be kept clinically clean, and the traditional rows of plates were replaced by cupboard space where cooking utensils and tableware could be kept without gathering dust and without becoming greasy from gas and frying.

The hygienic movement in architecture is also evident in other kitchens, designed by contemporary modernists. Le Corbusier (1887–1965) pointed out the importance of using materials that are easy to clean, and he adhered to this religiously in his housing design. In the kitchen at Villa Savoye, not only the walls but also the kitchen tables are covered with white tiles (see Fig. 3). The kitchen, which previously had the character of a "workshop", transformed into a "laboratory" — clinically clean. In this context, electricity was considered a great revelation. It was for example reflected in the Weissenhof exhibition in 1927, where Josef Frank thematized "the electrical kitchen". Electricity was highlighted as a clean source of energy, without smoke and dirt like gas or charcoal. Furthermore, electricity made the position of appliances independent of chimneys etc. The electric kitchen could therefore be arranged optimally on the basis of the functional analyses.

The Frankfurt kitchen (Fig. 4) was the most famous example, where the modernistic ideals of kitchen design were realized and mass produced [14, 15]. It was developed in 1926 by the Austrian architect Margarete Schütte-Lihotzky (1897–2000). She was part of a team around Ernst May, who in 1920 were tasked with building social housing in Frankfurt. Schütte-Lihotzky developed a number of standard kitchens, which were used in many houses [15]. The kitchens were simple and cheap, and they were constructed on the basis of an analysis of workflow and storage needs. Spatial dimensions were also determined in order to optimize workflow. In the Frankfurt kitchen the rooms were typically 1.90 m x 3.44 m and similarly narrow and deep kitchens became common in contemporary housing — also in Denmark (see Fig. 5).

Fig. 3 In Villa Savoye of 1928, the kitchen is designed in line with the contemporary ideals of clinical hygiene. Everything is white and the tiles on the kitchen table are easy to clean.

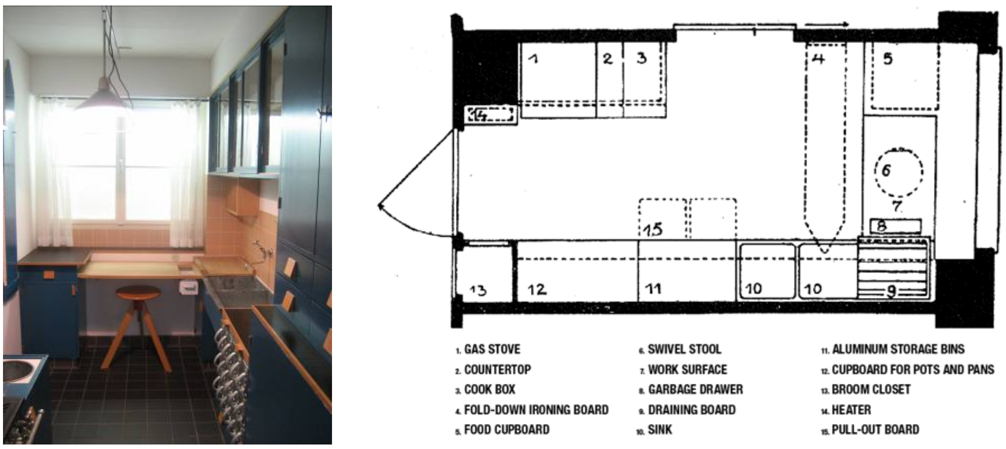

Fig. 4 The Frankfurt kitchen was designed for social housing in Frankfurt. It was the first mass-produced kitchen with a comprehensive design. Note the adjustable chair.

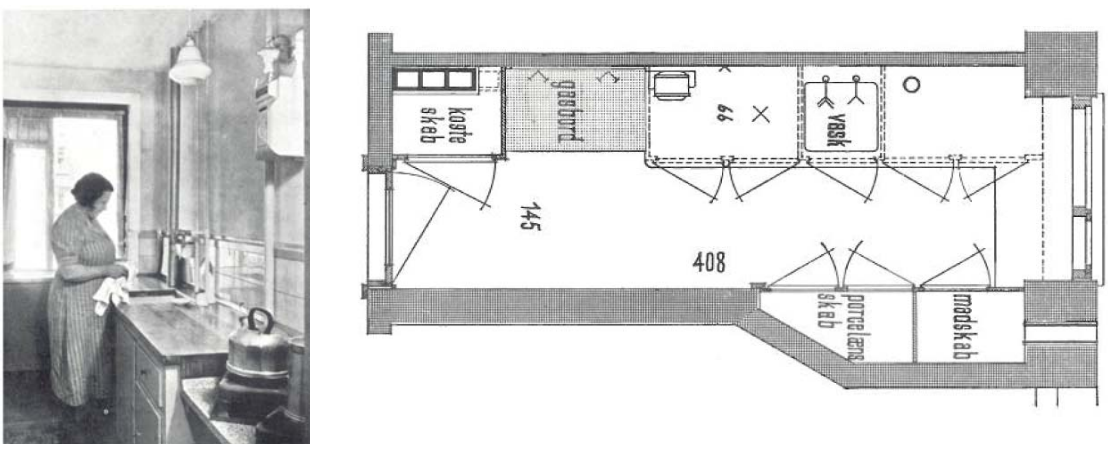

Fig. 5 A kitchen in the Danish social housing estate “Degnegaarden” from 1936. The deep and narrow space goes back to the Frankfurt kitchen. Degnegaarden was designed by Architects Cooperative - Alex Olsen, VagnKaastrup and Ole Buhl.

In pure modernism the individual space in housing was optimized in relation to one specific function, and rationalization efforts were to dispel anything that was not related to traditional kitchen work, i.e., anything other than cooking and dishwashing. However, in smaller houses this requirement was often compromised. Schütte-Lihotzky developed a range of multifunctional solutions, such as a bathtub with a lid that could double as workstation when not in use [15]. On the one hand, inventive and innovative, on the other hand a sign that Schütte-Lihotzky still had roots in the traditional use of the kitchen for more than just cooking.

Modernist ideals of kitchens arrived rapidly in Denmark. It was for instance expressed by Edward Heiberg (1897–1958), one of the leading Danish functionalists. Kitchen work was in focus when Heiberg built a house for his wife and himself in 1925. They had no servants, and as stated by Heiberg, it was therefore important that it should be easy for his wife to cope with the household chores. Heiberg continued working with kitchens, as an architect, as well as a researcher. His motto for kitchen design was: "Not one unnecessary step" [17].

Despite being politically active and supporting equality between the sexes, Heiberg had no doubt about who was responsible for the household in his own home. Similarly the location of kitchens in modernistic white villas usually expresses a clear continuation of the division between masters and servants — despite the modernists' effort to break down the hierarchical social structure. The rooms for servants are located on the lower floor, together with other secondary rooms such as storage rooms, laundry room, etc.

Thus, wealthy families' kitchens were still a workplace for servants, but many middle-class families, who could no longer afford a staff, felt embarrassed about having to work in the kitchen themselves [3]. To those women who reluctantly worked in their own kitchen (as the servants disappeared), cooking was a chore [4]. In the general population, kitchen work was still associated with low status, and the kitchen continued to be regarded as a secondary space. It was hidden away in relation to the more presentable spaces of the dwelling, and there was often more than one door between the kitchen and dining room.

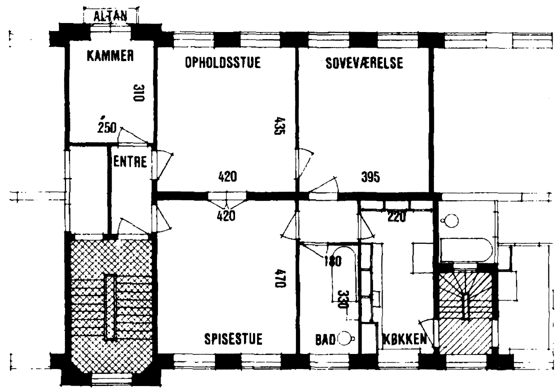

Fig. 6 The Danish housing estate, "Classens Garden" built in 1925. The apartment is very well equipped compared with other contemporary houses, for instance with a large bathroom with bath and a WC. The kitchen is located in the rear of all spaces with access from dining room through a corridor.

4. Danish Kitchens — Functionalism in the 1950s

After the Second World War, Europe had to be rebuilt and in Scandinavia the ideals of the welfare society were to be realized. In this context there was a socio-economic interest in getting more women into the labor market. By 1951 more than 20 percent of married women in Denmark worked outside the home. For comparison, this had only been the case for six percent in 1930 [18]. A study from 1954 showed that men's presence in the kitchen was still limited [14], and consequently there was a strong need to facilitate the housewife's domestic work.

However, only working class women had joined the labor market in earnest [18]. The middle-class families established themselves in the nuclear family with a housewife. The housewife was in charge of all domestic work, and as the families could no longer afford servants, she was alone in her kitchen. The kitchen, which had previously been the domain of the staff, was now the woman's room. This is reflected in the kitchen's location in the dwelling. In contrast to the pre-war kitchens, reserved for servants and hidden away, the kitchen now became a more integral part of the dwelling.

However, the kitchen was still not a part of the representative space. It was still a workplace for the housewife, and when guests came, she took off her apron, closed the door to the kitchen and welcomed the guests in the living rooms. There was still not much prestige in kitchen work and this was reflected in housing architecture. Kitchens were relatively small, they were designed for specific functions around cooking and washing — and you could close off the kitchen with a door.

In continuation of attempts in the 1920s and 1930s to develop functional and efficient kitchens, kitchens in the 1950s were also regarded as practical spaces [4]. Several measurements were made relating to space needs and room conditions in kitchens. This was partly as a continuation of the standardization processes, which enjoyed good conditions for growth in a post-war period with extensive housing shortages, and partly in an effort to facilitate domestic work and free female labor, so that women could participate in the labor market.

In Denmark Heiberg remained a leading figure in the debate on kitchen design and organization. In 1947 he developed a standardized kitchen for the Association of Social Housing and demonstrated that money could be saved by standardization: The kitchen was 20% cheaper than similar kitchens erected on site [17]. At the Danish Building Research Institute, which was established in 1947, studies of conditions related to work in the kitchen were substantial research tasks. Kitchenwork was studied and divided into a number of sub-functions such as "washing", "cooking", "preparing food" etc, and the need for storage was identified. The clear division between the different functions had hygienic advantages and can be seen as a direct extension of the modernist hygienic ideals from the pre-war period, but more important was the time-saving potential. Time studies showed the amount of time that women spent in the kitchen, and that this time could be reduced through rational design.

The same functional perspective determined the location of the kitchen in the dwelling. In dwellings from the 1950s, the kitchen is no longer hidden away in a distant corner of the home. It is typically located next to the entrance hall (meaning that heavy shopping bags can quickly be put down on the kitchen table), and with direct access to the dining room (so that food and plates do not have to be carried too far).

Actually, reductions in time were not only achieved through the physical layout, but also the handling of shopping and cooking were rationalized and industrialized. Where government information on food and cooking today is typically about health, contemporary information focused on reductions in time and utilization of new technical aids. For instance, the Danish Households' Council [Statens Husholdningsråd] conducted studies on how much time a housewife could save by serving canned soup and machine-peeled potatoes [11].

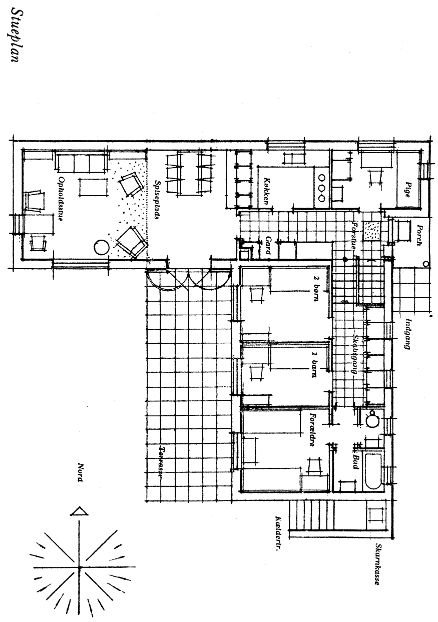

Fig. 7 Typical Danish detached housing from the 1950s. The dwelling is relatively small, as was dictated by governmental regulations, and the space in the kitchen is similarly small compared with today's standard. The kitchen is functionally placed in the house — near the entrance hall and close to the dining room.

In the 1950s a softening took place regarding the modernists' concept of the mono-functional space designed solely for cooking and dishwashing. This was partly due to a series of studies conducted at the Danish Building Research Institute in the early 1950s. Research surveyed residents' use of their kitchens in contemporary housing, and the residents were asked whether there was anything they wanted to change. They replied that the kitchens were too small and that housewives wanted a small dining area in the kitchen.

The mono-functional space did not accommodate the life led by a modern nuclear family. The housewife served as the family hub, and it became clear that the concept of the mono-functional room was not so functional after all. The housewife had many functions besides cooking to take care of, for example helping the children with their homework, and the narrow spaces of the 1930s were criticized. On this background, Edvard Heiberg designed kitchens with small dining tables in the Copenhagen housing estate, "Bellahøj" (1950–1954). In the housing estate "Tingbjerg" (1955), another famous Danish architect, Steen Eiler Rasmussen, did likewise (see Fig. 8).

Thus, the dining kitchens of the 1950s were initially functionally justified. This is evident from a report published by The Danish Social Housing Association in 1949. The report states that a place for eating should be designed into the kitchen, but should not be so spacious as to detract from the functions of the living room [17]. The dining area in the kitchen was not meant to be a place for socializing, but as a practical set-up that made it easier for the housewife to watch the children and help them with their homework while cooking. Nevertheless, the kitchen dining area brought a lot of life into the kitchen and informal socializing developed. This was to have a great impact on the further development of the kitchen.

5. Kitchen in the 1960s and 1970s

In the early 1960s the nuclear family was still the societal ideal, and although women had increasingly entered the labor market, they still took care of the housekeeping at home. The kitchen remained the women's domain, but they were not alone in their kitchen anymore. A dining area as a part of the kitchen was becoming popular, and the dining table, which in the 1950s usually consisted of a small table in a cramped corner, had become larger.

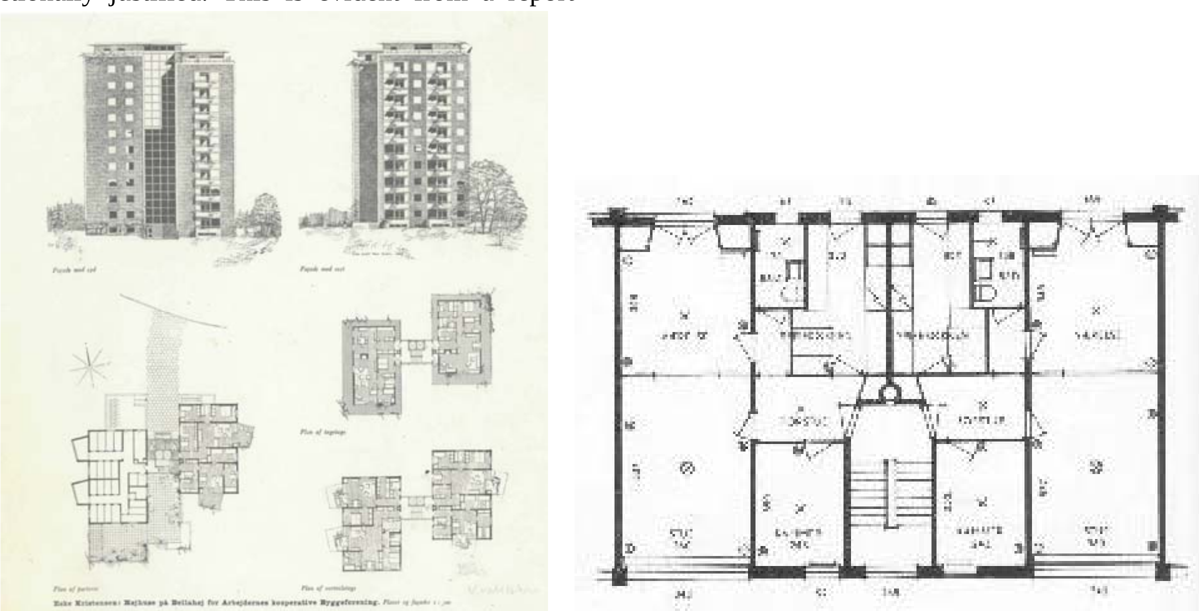

Fig. 8 Left: Bellahøj designed by Edward Heiberg et al. Right: Housing plan from Tingbjerg designed by Steen Eiler Rasmussen.

Thus a new view on the kitchen developed. The kitchen was no longer a functional workspace, and the dining area in the kitchen was no longer seen only as a practical measure. In many homes the dining area in the kitchen developed into a cosy space for social activities. There was a special atmosphere in the kitchen, when the heat from hot plates and the smell from the oven filled the room. Eating and talking unfolded side by side with kitchen work, and an informal atmosphere developed in the kitchen. Initially, the kitchen retained its workspace atmosphere and was still not seen as a representative place. Danish kitchens of the 1960s were informal and practically furnished, and thus became a place where the family was together in a friendly and relaxed manner.

When guests were invited, they were still not invited into the kitchen, but during the week the dining room stood empty. The dining area in kitchens grew, and as it was now often located near the dining room, it felt strange to have two dining tables standing only a few meters apart. Obviously the next step was to break down the wall between the kitchen and the dining room [16]. The kitchen-dining area was born.

Thus, the kitchen and cooking came out of hiding. The kitchen became a central space in the house, and cooking became a visible part of everyday life. However, initially this did not lead to sophisticated kitchen design or the conversion of the kitchen into a new "best parlor". Quite the contrary, cooking was carried out with doughy hands and floury arms, and along with cooking utensils and kitchen appliances a relaxed atmosphere was created in the kitchen. This was perfectly inline with the rebellion against bourgeoisie correctness that took place in the 1970s.

Thus, the kitchen was still a practical workspace. However this should not lead to the misconception that kitchens had no representative value. This was very much the case, but it was not the aesthetics of the room that scored points. In contrast, the quality of the kitchen was in its informal character and the influence of this on the rest of the dwelling.

The youth rebellion took place in 1968, and many people felt that essential qualities were lost as a consequence of societal modernization. Economic status had become too dominant and in the search for values of more fundamental character, pre-modern society came into focus. Urban planners looked back, and in traditional rural settlements they found a social life that seemed to have been lost in the modern city. Also architects looked back and found inspiration in traditional housing: In a typical book from 1977 an American architect described, how the kitchen in Saxon dwellings from 900 BC was a central space in the houses and served as the true "living room" [4]. Similar qualities were found by Danish architects in Nordic farm kitchens.

Looking back in time, the social significance of cooking and sharing a meal was rediscovered. A shared meal is one of the oldest exchange relationships between people, and many traditional rituals involve eating and drinking [13]. It was in this light that communal eating became important in the Danish community houses of the 1970s. They were set up in order to create social qualities and experiences between people. It was also time-saving when the residents in the communities took turns at cooking the meals, but the goal was not to increase societal production, but rather to allow time to be together.

All contemporary Danish low-density settlements had a common-house with a large kitchen. However, these kitchens were not installed at the expense of the kitchen in individual dwellings. The kitchen-dining area was an important space in the development of the family's sense of cohesion and it was a place to gather, where all family members could be heard.

Finally, the more central location of the kitchen within the dwellings of the 1970s is explained by changing gender roles. In many families the man increasingly began to take part in household work, and it is hardly a coincidence that at the same time kitchen work became visible in everyday life. The development of the exhaust hood that exhausts the smell of cooking and frying, facilitated this development. The delimiting walls could disappear, and the open kitchen-dining area was made possible.

This development of collective lifestyles, community houses and changing gender roles did not affect all families in the same way, but the ideals about kitchen design were nonetheless spread widely in Danish housing; in social housing as well as in detached houses. For instance in "Ishøj" — one of the largest contemporary social housing estates in Denmark — the individual dwellings were consistent with the ideals described. The open kitchens in Ishøj (see Fig. 9) are large and the dining table in the area between the kitchen and the sofa group is spacious, with room for at least six people.

6. 1980s until Today — Consumerism and Lifestyle Kitchens

It is hard to point to one overarching trend in the architecture of this period. The architectural development took many directions, postmodernism made a break with modernism's functional analysis, and architecture was freed of its moral obligation. With the liberation of architectural design, it became obvious that personal taste was often crucial when consumers had to choose from a plethora of products, all covering the same functional needs [15]. Moreover it became increasingly clear that the design of products reflected values, and thus the products indirectly came to be expressive of those who bought the products. Choice of design became a matter of personality and identity [15].

Fig. 9 Danish Social Housing in Ishøj from 1973. The spacious kitchen is part of the living area, and the dining table gives room for at least six people.

A dwelling could therefore no longer be regarded as a "machine to live in" — and correspondingly a kitchen was not only a room for cooking. The kitchen was a designed product, reflecting opinions and personality, and not necessarily built to last as long as the dwelling itself. Since the functional properties no longer reigned supreme, a kitchen could be replaced — even though it still functioned well — if it was not in line with the residents' preference of taste. This kind of renewal and decoration in the dwelling may be called "lifestyle renovations" [2], and today's kitchens have been given a similar name: "lifestyle kitchens".

The dwelling has developed into an important place for residents' self-realization as well as a reflection of their personal identity, and kitchen design, details, materials and aesthetic take precedence over the functional [6]. The dwelling has turned into a mirror into which we look to find ourselves. Who are we, and what do we want to be like? That is what we seek when we decorate our dwelling and when we convert our kitchen. It is about finding your own style — about finding yourself [2].

Advertising agencies know this. An advertising campaign for a large Danish kitchen manufacturer (Invita) sells the idea of a kitchen as an individual and unique product. "It is not an 'Invita kitchen', it's a Mette and Lars kitchen," says the advertisement. Similarly, kitchen dealers say that they never supply two identical kitchens [6]. It is explained that the spaces to be furnished are different, the buyers have varying needs and financial situation, and that various materials, details, shapes and colors can be combined [6]. The question remains whether this differs from older kitchens? Modern kitchens are more standardized than ever before, and it can also be argued that older kitchens made specifically for a particular room were more individual than the new ones.

It is not the major technical innovations or architectural changes that characterize the kitchens of the two last decades. The kitchen-dining area is still the preferred type of kitchen, its location in the dwelling is equivalent to that which was developed in the 1970s, and the kitchen is still considered the central space in the house. Later literature on kitchen decor is not about new functional requirements and structural changes. Focus is rather on the kitchen “style”. This is often apparent in categorized sections that present various styles: High-tech kitchen, the minimalist kitchen, the romantic country kitchen, etc. A consistent, general style of the period cannot be identified, but it can be pointed out that style is extremely important [7].

In general, the dwelling has rediscovered the representative character of the past, and this has become apparent in the design and shape of the kitchen. Where the kitchen of the 1970s was thought of as a workplace, able to tolerate the tough nature of kitchen work, kitchens in recent decades have seen an entirely different aesthetic approach. Where the informal nature of the kitchen was reflected in the adjoining rooms in the 1970s, today the representative qualities of the living rooms have influenced the kitchen. Light woods, brushed steel, and polished granite have become some of the preferred materials for exclusive kitchens (the use of the delicate materials was made possible because goods from the supermarket arrive in purified and processed form).

Today’s lifestyle kitchens send out strong signals, and they work as a framework for self promotion. Like for instance, when guests are welcomed on a Friday night: a roast is in the oven, red wine has been poured, and a shiny kitchen bears witness that the host is in control of his life and apparently manages to cook in a trendy way. With the increased prosperity in society, focus is no longer on food as necessary for survival, and focus is less on the meal as a framework for social interaction. In today’s lifestyle kitchen food expresses a family in control and with ability to appreciate and prepare fine cooking. Work in the kitchen is no longer hidden away behind closed doors.

However, repeatedly the question is being asked of whether today’s large and prestigious kitchens actually form the setting for cooking. It has been argued, that our kitchens have become more and more spacious as we eat more and more fast food — and thus spend less and less time cooking. As early as the 1990s, the Italian scientist and designer Mondadori discussed this development and he pointed out that current kitchens reflect two concurrent trends. On the one hand he sees the emergence of “the fast-food home”, where residents are increasingly buying ready-made meals, heating them in the microwave oven and eating them in front of the television. This can be seen as a further development of the trends of the 1950s, when the use of canned or other ready-made dishes was highlighted for the potential time savings.

On the other hand, Mondadori sees signs of the emergence of “the convent home”, where cooking and meals are increasingly seen as a ritual part of a social community. Here, delicious recipes and culinary experiences are paramount, and “slow food” cooking is considered as part of a lifestyle rather than an abomination that should to be reduced and eliminated. The trend can be seen as a continuation of the 1970s organic movements and communities’ rediscovery of cooking and meals as more than just putting food into your mouth. In this light, the kitchen becomes a space of the senses, where the experiences of exotic spices, colorful vegetables, the texture of materials and delicate tastes are some of the ingredients.

According to Mondadori, the two trends exist side by side — not only in the sense that different families choose to live in different ways and their neighbors do not necessarily share the same lifestyle, but also that trends can co-exist within one and the same family. The shift can happen between lunch and dinner, during the week, on weekends, etc. “With the same furniture and the same equipment, you can returnto medieval times, or you can move toward Star Wars”, writes Mondadori, seductively. The kitchen is open for dreams and these dreams will continue in the 21st century.

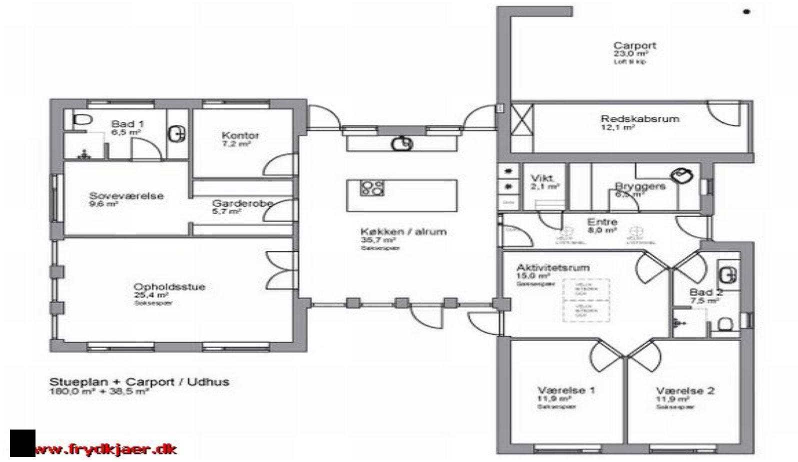

Fig. 10 Typical Danish detached housing from 2011. The kitchen is — as in the previous period — considered the central space in the house. However, today there is an increased emphasis on the kitchen "style".

7. Conclusion

This paper has shown how societal and cultural trends (for instance health, food culture, gender, sustainability, consumerism class, wealth, technology etc.) have influenced architectural design over the last 100 years. This has been done by focusing on the layout of the kitchen and kitchen design in European and Danish housing.

The following changes have been identified:

One hundred years ago, the kitchen of the bourgeoisie and the middle class was only used by servants and other employees — the kitchen was not designed for the residents. Therefore, the design of the kitchen and work in the kitchen were not associated with any prestige. Today we spend an enormous amount of money on decorating and designing our kitchens. One of the reasons for this is that the kitchen has become an important showcase for lifestyle and identity.

In the early 20th century, major efforts were made to streamline the workflow in the kitchen in order to save time. An important objective was to release the female workforce for the labor market. These trends are still detectable in today's kitchens — in the form of ready-made meals, microwaves and fast food. But at the same time "slow food" has become a trend. "Time" is a valuable asset today, and it is associated with high status to have the time, personal ability to cope and reserves of energy to prepare good food with the emphasis on quality.

At the beginning of the century, the kitchen was a secondary space. In villas the kitchen was situated side by side with the coalstore and servants' rooms in the basement, and in the large residential blocks in the city they were well hidden away in a far corner of the apartment. During the 20th century, the kitchen moved even further into the spotlight, and today it has developed into a central room of the home with great social qualities, and a lot of money is spent on the aesthetic appearance of the kitchen.

So fundamental changes have taken place in the kitchen over this relatively short period of time. Our view of the kitchen has undergone drastic changes and the physical location and layout of the kitchen have also developed dramatically. This can serve as a reminder that kitchens as well as housing will continue to change. Although many people have a firm concept of what a dwelling is, in fact the dwelling is changing constantly, both physically and mentally.

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A Refined Formula for the Allowable Soil Pressure Using Shear Wave Velocities

Semih S. Tezcan and Zuhal Ozdemir
Bogazici University, Bebek, Istanbul, Turkey

Abstract: Based on a variety of case histories of site investigations, including extensive bore hole data, laboratory testing and geophysical prospecting at more than 550 construction sites, an empirical formulation is proposed for the rapid determination of allowable bearing pressure of shallow foundations in soils and rocks. The proposed expression corroborates consistently with the results of the classical theory and is proven to be rapid, and reliable. Plate load tests have been also carried out at three different sites, in order to further confirm the validity of the proposed method. It consists of only two soil parameters, namely, the in situ measured shear wave velocity and the unit weight. The unit weight may be also determined with sufficient accuracy, by means of other empirical expressions proposed, using P or S — wave velocities. It is indicated that once the shear and P-wave velocities are measured in situ by an appropriate geophysical survey, the allowable bearing pressure as well as the coefficient of subgrade reaction and many other elasticity parameters may be determined rapidly and reliably.

Key words: Shear wave velocity, shallow foundations, allowable bearing pressure, dynamic technique, soils and rocks.

1. Introduction

Professor Schulze [1], a prominent historical figure in soil mechanics and foundation engineering in Germany, stated in 1943 that "For the determination of allowable bearing pressure, the geophysical methods, utilising seismic wave velocity measuring techniques with absolutely no disturbance of natural site conditions, may yield relatively more realistic results than those of the geotechnical methods, which are based primarily on bore hole data and laboratory testing of so-called undisturbed soil samples".

Since that time, various significant contributions have been made to solving geotechnical problems by means of geophysical prospecting. The P-wave velocities, for instance, have been used to determine the unconfined compressive strengths and modulus of elasticity of soil samples by Coates [2]. Hardin and Black [3], and also Hardin and Drnevich [4], based on extensive experimental data, established indispensable relations between the shear wave velocity, void ratio, and shear rigidity of soils. Similarly, Ohkubo and Terasaki [5] supplied various expressions relating the seismic wave velocities to weight density, permeability, water content, unconfined compressive strength and modulus of elasticity.

The use of geophysical methods in soil mechanics has been extensively studied for the purpose of determining the properties of soils and rocks by Imai and Yoshimura [6], Tatham [7], Willkens et al. [8], Phillips et al. [9], Keceli [10, 11], Jongmans [12], Sully and Campanella [13], and Pyrak-Nolte et al. [14]. Imai and Yoshimura [6] proposed an empirical expression for the determination of bearing capacity q_f and/or q_a as

$$nq_a = q_f = V_s^{2.4} /(1590) \ (\text{kPa}) \quad (1)$$

which yields values unacceptably much higher than the classical theory as will be evident in next section. Campanella and Stewart [15], determined various soil parameters by digital signal processing, while Butcher and Powell [16], supplied practical geophysical techniques to assess various soil parameters related to ground stiffness. An empirical expression is also proposed by Abd El-Rahman [17], for the ultimate

Corresponding author: Semih S. Tezcan, professor, research field: civil engineering. E-mail: tezokan@gmail.com.

bearing capacity of soils, using the logarithm of shear wave velocity.

A series of guidelines have been also prepared in this respect by the Technical Committee TC 16 of IRTP, ISSMGE [18], and also by Sieffert [19]. Keceli [11], Turker [20], based on extensive case studies, supplied explicit expressions for the allowable bearing pressure, using shear wave velocity. In this paper, the earlier formula presented by Tezcan et al. [21], has been calibrated and improved with the soil data of 550 construction sites. Massarsch [22] determined deformation properties of fine-grained soils from seismic tests. As to the in situ measurement of *P* and *S* – wave velocities, various alternate techniques are available as outlined in detail by Stokoe and Woods [23], Tezcan et al. [24], Butcher et al. [25], Richart et al. [26], Kramer [27], Santamarina et al. [28].

2. Theoretical Basis for the Empirical Expression

In order to be able to arrive at a particular empirical expression for the allowable soil pressure q_a — underneath a shallow foundation, the systematic boundary value approach used earlier by Keceli [11] will be followed. The state of stress and the related elastic parameters of a typical soil column is shown in Fig. 1. Considering a foundation depth of D_f with a unit cross-sectional area of A = 1, the typical form of the compressive ultimate bearing capacity at the base of the foundation nothing but only as a format, may be written approximately as;

$$q_f = \gamma D_f \tag{2}$$

$$q_a = q_f/n = \gamma D_f/n \tag{3}$$

where q_f = ultimate bearing capacity at failure, γ = unit weight of soil above the base of the foundation, q_a = allowable bearing pressure, and n = factor of safety. In order to be able to incorporate the shear wave velocity V_{s2} into the above expressions, the depth parameter D_f will be expressed as velocity multiplied by time as;

$$D_f = V_{s2}\, t \tag{4}$$

in which, the V_{s2} is purposely selected to be the shear wave velocity measured under the foundation, t = is an unknown time parameter. The time parameter t is introduced herein just as a dummy parameter in order to keep consistency in appropriate units. Substituting Eq. (4) into Eq. (3), yields

$$q_a = \gamma V_{s2}\, t \,/\, n \tag{5}$$

The unknown time parameter t, will be determined on the basis of a calibration process. For this purpose, a typical 'hard' rock formation will be assumed to exist under the foundation, with the following parameters, as suggested earlier by Keceli [11];

$$q_a = 10\ 000\ \text{kN/m}^2,\ V_{s2} = 4\ 000\ \text{m/sec},$$
$$\gamma = 35\text{kN/m}^3,\ n = 1.4 \tag{6}$$

Substituting these numerical values into Eq. (5), we obtain $t = 0.10$ sec, thus;

$$q_a = 0.1\ \gamma\ V_{s2}/n \tag{7}$$

This is the desired empirical expression to determine the allowable bearing pressure q_a, in soils and rocks, once the average unit weight, γ, for the soil layer above the foundation and the in situ measured V_{s2} — wave velocity for the soil layer just below the foundation base are available. The unit of V_{s2} is in m/sec, the unit of γ is in kN /m^3 , then the resulting q_a – value is in units of *kPa*. The unit weight values may be estimated using the empirical expressions;

$$\gamma_p = \gamma_0 + 0.002\ V_{p1} \tag{8a}$$

and $$\gamma_s = 4.3\ V_{s1}^{0.25} \tag{8b}$$

as proposed earlier by Tezcan et al. [21], and by Keceli [29], respectively. The second expression is especially recommended for granular soils, for which the measured V_{s1} values represent appropriately the degree of water content and/or porosity. The wave velocities must be in units of *m/sec*. The only remaining unknown parameter is the factor of safety, *n*, which is assumed to be, after a series of calibration processes, as follows:

$$n = 1.4\ (\text{for } V_{s2} \geq 4\ 000\ \text{m/sec}),$$
$$n = 4.0\ (\text{for } V_{s2} \leq 750\ \text{m/sec}) \tag{9}$$

The calibration process is based primarily on the reference q_a — values determined by the conventional Terzaghi method, for all the data sets corresponding to the 550 — construction sites considered. For V_{s2} values greater than 750 m/sec and smaller than 4000

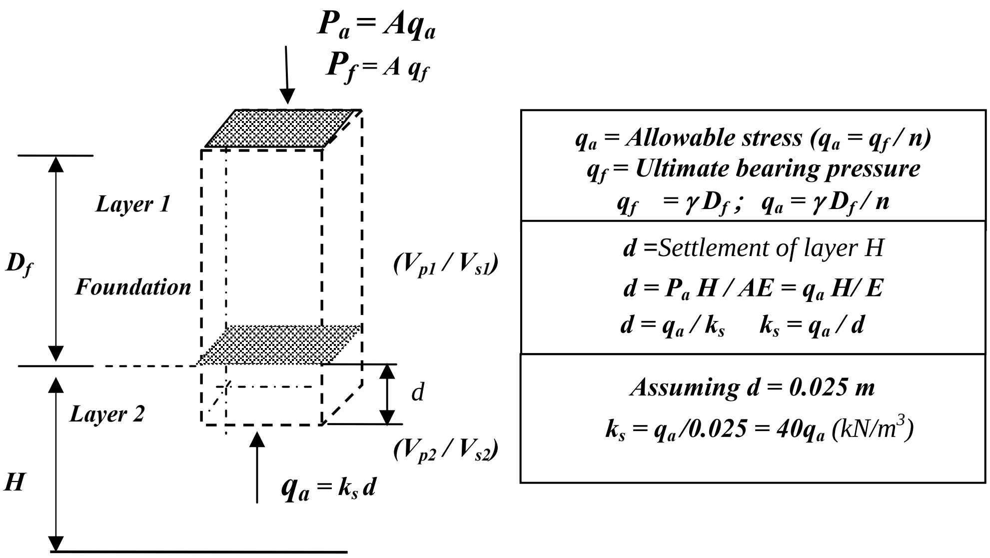

Fig. 1 Soil column and related parameters.

m/sec a linear interpolation is recommended. The engineering rock formations are assumed to start for $V_{s2} > 750$ m/sec. The factors of safety, as well as the empirical allowable bearing pressure expressions, for various soil (rock) types, are given in Table 1. It is seen that three distinct ranges of values are assumed for n = factor of safety. For soil types with $V_{s2} \leq 750$ m/sec the factor of safety is n = 4, for rocks with $V_{s2} \geq 4000$ m/sec, it is n= 1.4. For other intermediate values of shear wave velocity, linear interpolation is recommended. The validity of these values has been extensively checked and calibrated by the soil data at 550 construction sites. The relatively higher value of factor of safety assumed for soils is deemed to be appropriate to compensate the inaccuracies and gaps existing in the measured values of shear wave velocity. In fact, Terzaghi and Peck [30] states that "The factor of safety of the foundation with respect to breaking into the ground should not be less than about 3".

It is determined by Terzaghi and Peck [30] also that the width of footing, *B*, has a reducing influence on the value of allowable bearing pressure for granular soils. Therefore, a correction factor β is introduced into the formula, for sandy soils only, as shown in the third line of Table 1. The proposed values of this correction factor, for different foundation width *B*, are as follows:

$$\beta = 1.00 \qquad \text{for } (0 \leq B \leq 1.20 \text{ m})$$
$$\beta = 1.13 – 0.11\,B \qquad \text{for } (1.2 \leq B \leq 3.00 \text{ m})$$
$$\beta = 0.83 - 0.01\,B \qquad \text{for } (3.0 \leq B \leq 12.0 \text{ m}) \quad (10)$$

3. Coefficient of Subgrade Reaction

The shear wave velocity may be used successfully to determine k_s = coefficient of subgrade reaction of the soil layer just beneath the foundation base by making use of the expressions given in Fig. 1. The coefficient of subgrade reaction k_s, is defined, similar to the definition of spring constant in engineering

Table 1 Factors of safety, n, for soils and rocks(1)

Soil type	V_s – range (m/sec)	n	q_a (kN/m^2)
"Hard" rocks	$V_s \geq 4000$	n = 1.4	$q_a = 0.071\,\gamma\,V_s$
"Soft" rocks	$750 \leq V_s \leq 4000$	$n = 4.6 – 8.10^{-4}\,V_s$	$q_a = 0.1\,\gamma\,V_s / n$
Soils	$750 \geq V_s$	n = 4.0	$q_a = 0.025\,\gamma\,V_s\,\beta$

(1) Linear interpolation is applied for $750 \leq V_s \leq 4\,000$ m/sec. β correction factor is used for sands only (Eq. 10).

mechanics, to be the necessary vertical pressure to produce a unit vertical displacement and expressed as:

$$k_s = q_a/d \quad (11)$$

For shallow foundations, the total vertical displacement is restricted to 1 inch =0.025 m, as prescribed by Terzaghi and Peck [30]. When, d = 0.025 m is substituted in Eq. (11), the coefficient of subgrade reaction becomes in units of kN/m^3 ;

$$k_s = 40q_a \quad (12)$$

$$\text{or} \quad k_s = 4\gamma V_{s2}/n \quad (13)$$

4. Elasticity Parameters

Once, V_{p2} and V_{s2} seismic wave velocities are measured, by geophysical means, for the soil layer No.2 just under the foundation, several parameters of elasticity, such as G = Shear modulus, E_c = Constraint modulus of elasticity, E = Modulus of elasticity (Young's modulus), E_k = Bulk modulus, and μ = *Poisson*'s ratio may be obtained easily. The Shear modulus, G, and the Constraint modulus, E_c, are related to the shear and P- wave velocities by the following expressions, respectively;

$$G = \rho V_s^2 \quad (14)$$

$$\text{and} \quad E_c = \rho\ V_p^2 \quad (15)$$

where, ρ = mass density given by $\rho = \gamma/g$. From the Theory of Elasticity, it is known that, E = the *Young*'s modulus of elasticity is related to E_c = the Constraint modulus and also to G = the Shear modulus by the following expressions:

$$E = E_c (1 + \mu)(1 - 2\mu)/(1 - \mu) \quad (16)$$

$$E = 2(1 + \mu)G \quad (17)$$

Utilising Eqs. (14) and (15) and also substituting α , as

$$\alpha = E_c/G = (V_p/V_s)^2 \quad (18)$$

into Eqs. (16) and (17), we obtain

$$\mu = (\alpha - 2)/2(\alpha - 1) \quad (19)$$

$$\text{or,} \quad \alpha = (2\mu - 2)/(2\mu - 1) \quad (20)$$

The modulus of elasticity is directly obtained from Eq. (17) as;

$$E = (3\alpha - 4)\, G/(\alpha - 1) \quad (21)$$

The Constraint modulus E_c , may be also obtained in terms of α as ;

$$E_c = \alpha\ (\alpha - 1)E/(3\alpha - 4) \quad (22)$$

$$\text{or,}\ E_c = \gamma\ V_p^2/g \quad (23)$$

The Bulk modulus E_k, of the soil layer, may be expressed, from the theory of elasticity, as

$$E_k = E/3\ (1 - 2\mu) \quad (24)$$

$$E_k = (\alpha - 1)E/3 = \gamma\ (V_p^2 - 4V_s^2/3)/g \quad (25)$$

5. Case Studies

The allowable bearing pressures have been also determined at more than 550 construction sites in and around the Kocaeli and Istanbul Provinces in Turkey, between the years 2005–2010. At each construction site, by virtue of City by-law, appropriate number of bore holes were drilled, SPT counts conducted, undisturbed soil samples were taken for laboratory testing purposes, where shear strength -c, the internal angle of friction -ϕ, unconfined compression strength -q_u and unit weight -γ were determined. Subsequently, following the classical procedure of Terzaghi and Peck [30], the ultimate capacity and also the allowable bearing pressures were determined, by assuming the factor of safety as n = 3. For granular soils, immediate settlement calculations were also conducted, in order to determine whether the shear failure mechanism or the maximum settlement criterion would control the design.

The numerical values of the allowable bearing pressures, q_a, determined in accordance with the conventional Terzaghi theory, are shown by a triangular (Δ) symbol, in Fig. 2, where the three digit numbers refer to the data base file numbers of specific construction sites. Parallel to these classical soil investigations, the P- and S- wave velocities have been measured in situ, right at the foundation level for the purpose of determining the allowable bearing pressures, q_a , which are shown by means of a circle (o), in Fig. 2. Two separate linear regression lines were also shown in Fig. 2, for the purpose of indicating the average values of allowable bearing pressures determined by "dynamic" and "conventional" methods. In order to obtain an idea about the relative conservatism of the two methods, the ratios of allowable bearing pressures ($r = q_{ad}/q_{ac}$), as determined by the "dynamic" and "conventional" methods, have been plotted against the V_s – values in Fig. 3.

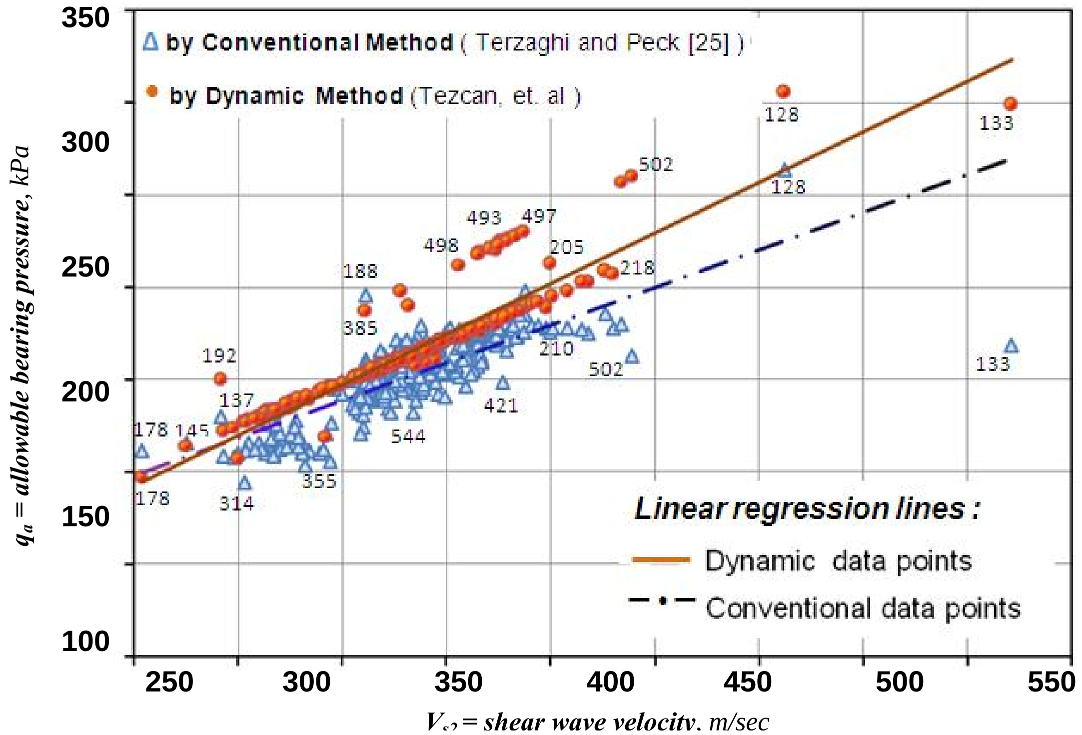

Fig. 2 Comparative results of "Conventional" and "Dynamic" methods.

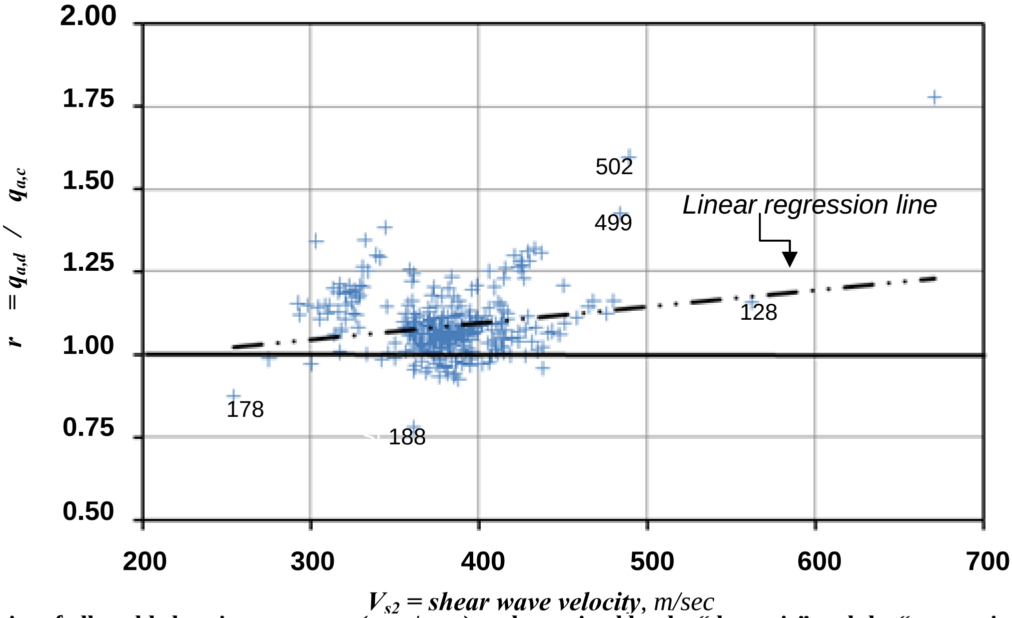

Fig. 3 Ratios of allowable bearing pressures ($q_{a,d}$ / $q_{a,c}$) as determined by the "dynamic" and the "conventional" methods.

It is seen that the linear regression line indicates for V_s – values smaller than 400 m/sec a narrow band of r = 1.03 to r = 1.12, which should be regarded as quite acceptable. The "dynamic" method proposed herein yields allowable bearing pressures slightly (on the order of 3 to 10 percent) greater than those of the "conventional" method for V_s – values smaller than 400 m/sec. In fact, the "conventional" method fails to produce reliable and consistent results for relatively strong soils and soft rocks, because it is difficult to determine the appropriate soil parameters c, and ϕ for use in the "conventional" method. At construction site Nos: 133, 134, 138, 139, 206, 207, 214, 215, 219, 502, 507 and 544, where the soil conditions have been mostly weathered andesite, granodiorite arena, greywacke, limestone, etc did not allow for the measurement of c and ϕ — values. Therefore, the use of "dynamic" method becomes inevitable for such strong soils with V_{s2} > 400 m/sec.

The list of soil parameters determined by in situ and also by laboratory testing through geotechnical prospecting, as well as the in situ measured V_p and V_s – velocities at each of the 550 construction sites, are too voluminous to be included herein. Those researchers interested to have access to these particular data base, may inquire from internet www.superonline.com, www.tezokan.com.

6. Seismic Wave Velocities

The seismic wave velocities have been measured using P – and S – geophones by means of a 24 – Channel Geometrics Abem – Pasi seismic instrument, capable of noise filtering. The P – waves have been generated by hitting 6 – blows vertically, with a 0.15 kN hammer, onto a 250 × 250 × 16 mm size steel plate placed horizontally on ground. For the purpose of generating S – waves however, an open ditch of size 1.4 × 1.4 × 1.4 m was excavated and then two steel plates were placed on opposite vertical faces of this ditch parallel to the conterline of the geophones. Using the same 0.15 kN hammer, 6 heavy horizontal blows were applied onto each of these vertical steel plates. The necessary polarity of the S – wawes was achieved by hitting these vertical steel plates horizontally in opposite directions, nonconcurrently.

7. Plate Load Testing

For purposes of correlating the allowable bearing pressures determined by various methods, plate loading tests have been carried out at three particular construction Sites Nos: 335, 502 and 544. The soil parameters c, q_u , and γ as determined by laboratory testing, as well as the P and S – wave velocities measured at site by geophysical prospecting are all shown in Table 3. A thick steel bearing plate of 316.2 mm × 316.2 mm = 0.10 square meter in size is used under the test platform of size 1.50 m by 1.50 m. The tests are carried out right at the bottom elevations of foundations. One half of the bearing pressure σ_0, which produced a settlement of s = 12.7 mm was selected as the allowable pressure q_a as shown in Fig. 4. It is seen clearly in Table 2 that the results of the

Table 2 Comparative evaluation of allowable pressures.

Site No Owner Lot Nos *(soil type)*	Various soil parameters ($\phi = 0$)						q_a = allowable pressure		
	$q_u^{(1)}$	D_f	c	γ_{lab}	V_{p2}	V_{s2}	Terzaghi(2) Eq. 26	Tezcan, et.al.(3) Eq. 7	Load test Fig.4
	kPa	*m*	*kPa*	*kN/m³*	*m/sec*	*m/sec*	*kPa*	*kPa*	*kPa*
335 Suleyman Turan 8 Paft./A/930 Pars. *(silty clay)*	172	1.50	86	18.9 $\gamma_0 = 16$	896	390	157	**173**	**180**
544 Ayhan Dede G22B/ 574/11 *(weathered diorite)*	190	1.50	95	18.0 $\gamma_0 = 16$	1 020	453	172	**204**	**208**
502 Ebru Çınar 30 L1C/ 440/8 *(clay stone)*	147	1.00	140	22.7 $\gamma_0 = 20$	1 210	489	248	**274**	**280**

(1) q_u = unconfined compressive strength; (2) Terzaghi and Peck (1976); (3) $q_a = 0.025\ \gamma_p\ V_s$ (Eq.7), n = 4.

Table 3 Results of numerical example (H = 15 m, V_{p2} = 700 m/sec, V_{s2} = 200 m/sec, c = 52 kPa, ϕ =0), (V_{p1} = 700 m/sec above the base).

Formula	Equation	Numerical calculations	Result	Unit
$\gamma_p = \gamma_0 + 0.002\ V_{p1}$ Laboratory	eqn (8a) -	$\gamma_p = 16 + 0.002\ (700)$ -	17.4[(1)] 17.2	kN/m^3 kN/m^3
n = 4 $q_f = c\ N_c + \gamma\ D_f\ \ N_q$ $q_f = 0.1\ \gamma\ V_{s2}$ $q_a = q_f / n$	Table 1 eqn (26) eqn (7) eqn (3)	$V_{s2} \leq 750$ m/sec $q_f = 52\ (5.14) + 17.2\ (2.9)\ 1$ $q_f = 0.1\ (17.4)\ 200$ $q_a = 348 / 4$	4 318 348 87	- kN/m^2 kN/m^2 kN/m^2
$k_s = 40\ q_a = 4\gamma\ V_{s2} / n$ $G = \gamma\ V_s^{\ 2} / g$	eqn (12) eqn (14)	$k_s\ \ = 40\ (87)$ $G = 17.4\ (200)^2 / 9.81$	3 480 70 948	kN/m^3 kN/m^2
$\alpha = (V_{p2} / V_{s2})^2$ $\mu = (\alpha - 2) / 2(\alpha - 1)$ $E = 2\ (1+\mu)\ G$	eqn (18) eqn (19) eqn (17)	$\alpha = (700 / 200)^2$ $\mu = (12.25 - 2) / 2(11.25)$ $E = 2\ (1.456)\ 70\ 948$	12.25 0.456 206 537	- - kN/m^2
$E_c = \gamma\ V_{P2}^{\ 2}\ \ / g$ $E_k = E / 3\ (1-2\mu)$ $E_k = E\ (\alpha - 1)/3$	eqn (15) eqn (24) eqn (25)	$17.4\ (700)^2 /\ \ 9.81$ $206\ 537 / 3\ (1-2\mu\ )$ $206\ 537\ (12.25-1) / 3$	870 000 774 417 774 514	kN/m^2 kN/m^2 kN/m^2
d = displacement	eqn (11)	$d = q_a\ \ / k_s = 87 / 3480$	0.025	m

(1) Result of Eq. (8a), γ = 17.4 kN/m^3 is used in all subsequent expressions.

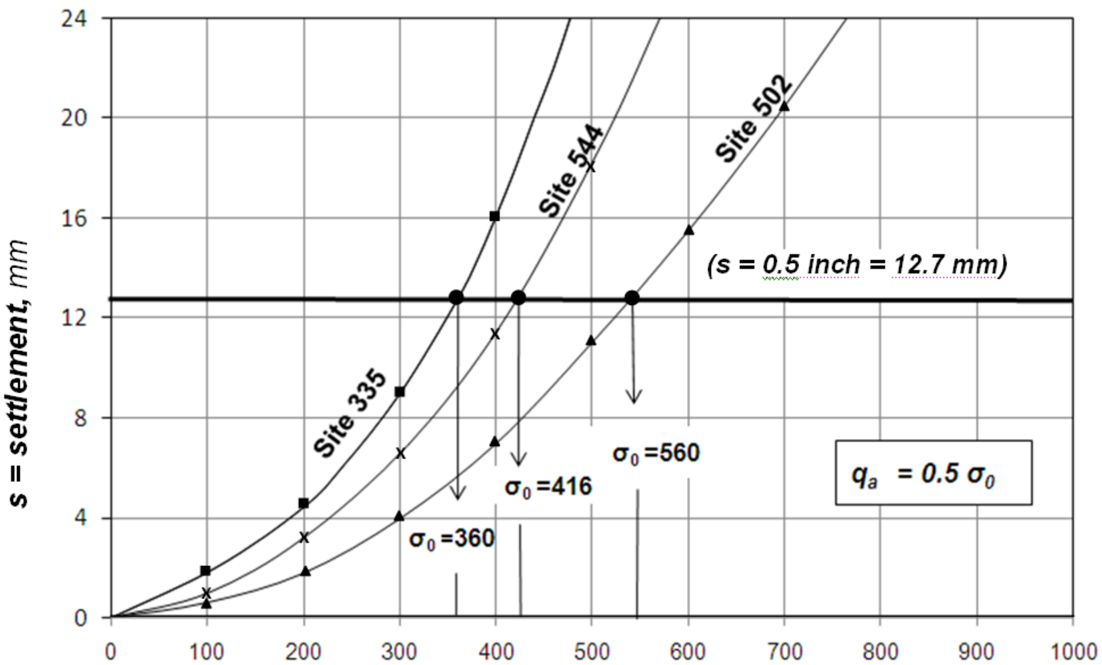

Fig. 4 Load test results at Sites No: 335, 502, and 544 (σ = pressure under the test plate, kPa; σ_0 = 2, q_a = pressure, which produces s = 12.7 mm).

proposed "dynamic" method using *P* and *S* – wave velocities are in very close agreement with those of the plate load testing. The allowable bearing pressures q_a, in accordance with the conventional theory assuming N_c = 5.14 and N_q = 1, are also calculated using

$$q_a = (cN_c + \gamma D_f\ N_q)/3.0 \tag{26}$$

8. Numerical Example

For purposes of illustration, a soft clayey soil layer of H = 15 m beneath a shallow strip footing of depth D_f = 2.90 m, width B = 1.30 m, is considered. The in situ measured seismic wave velocities are determined to be V_{p2} = 700 m/sec and V_{s2} = 200 m/sec, within the soil layer just below the foundation base. By coincidence, the P – wave velocity within the soil layer above the foundation base is also measured to be V_{p1} = 700 m/sec. A comprehensive set of classical soil investigations, including a number of bore hole data and laboratory testing exist for this particular site, together with the numerical values of various soil parameters (c = 52 kPa, and ϕ = 0), including the bearing pressure capacity determined to be q_f = 322 kPa by the conventional method of Terzaghi and Peck [30]. Therefore, the validity and the reliability of the proposed empirical formulae have been rigorously verified. Calculation of some elasticity parameters, using the empirical expressions presented herein, is summarised in Table 3.

9. Discussion on the Degrees of Accuracy

The degrees of accuracy of the proposed "dynamic" method are quite satisfactory and consistent as attested rigorously at more than 550 construction sites. The conventional approach however, depends heavily on the degrees of accuracy of in situ and laboratory determined soil parameters. In fact, the allowable bearing pressure calculations are very sensitive to the values of c, and ϕ, determined in the laboratory using so-called "undisturbed" soil samples, which may not necessarily represent the true in situ conditions. This may explain the reason why at a number of construction sites, some inconsistent and erratic results for q_a are obtained using the classical theory, as already depicted in Fig. 2, because the laboratory measured c, and ϕ - values differed considerably from one soil sample into the other. The "Point Load" tests (Fig. 4) of rock samples have been carried out for V_{s2} - values greater than 400 m/sec as recommended by Hunt [31].

10. Conclusions

The P and S – wave velocities are most powerfull soil properties representing a family of geotechnical soil parameters, ranging from compressive and shear strengths to void ratio, from subgrade coefficient to cohesion etc,

Once the shear and P – wave velocities are measured, the allowable bearing pressure, the coefficient of subgrade reaction, various other elasticity parameters, as well as the approximate values of the unit weight are rapidly and economically determined, using relatively simple empirical expressions. Bore hole drilling and laboratory testing of soil samples including the "point load" method of rock samples, may be beneficially utilised for correlation purposes.

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Structural Stress Identification Using Fuzzy Pattern Recognition and Information Fusion Technique

Jun Teng, Ting Zhang and Wei Lu
Shenzhen Graduate School, Harbin Institute of Technology, Shenzhen, China

Abstract: In order to ensure the service security of space structures under wind load, the stress identification method based on the combination of fuzzy pattern recognition and information fusion technique is proposed, in which the measurements of limited strain sensors arranged on the structure are used. Firstly, the structure is divided into several regions according to the similarity and the most unfavorable region is selected to be the key region for stress identification, while the different numbers of the strain sensors are located on the key region and the normal regions; secondly, the different stress distributions of the key region are obtained based on the measurements of the strain sensors located on the key region and the normal regions separately, in which the fuzzy pattern recognition is used to identify the different stress distributions; thirdly, the stress distributions obtained by the measurements of sensors in normal regions are selected to calculate the synthesized stress distribution of the key region by D-S evidence theory; fourthly, the weighted fusion algorithm is used to assign the different fusion coefficients to the selected stress distributions obtained by the measurements of the normal regions and the key region, while the synthesized stress distribution of the key region can be obtained. Numerical study on a lattice shell model is carried out to validate the reliability of the proposed stress identification method. The simulated results indicate that the method can improve identification accuracy and be effective by different noise disturbing.

Key words: Stress identification, Fuzzy pattern recognition, information fusion technique.

1. Introduction

Large space structures are usually the important symbols in cities, which are wind-sensitive because of their small damping ratio and low frequency in vibration. Therefore, the safety and reliability of the large space structures under wind load is one of the most important research problems. Structural health monitoring is a method which can obtain the structural responses and give the estimation of the working status of the structure, while different types of sensors are arranged on the structure. Recently, the researchers [1–5] put emphasis on realizing objectives and functions of structural health monitoring system using limited measurements of sensors. For example, Ming Liu *et al.* [6] assessed the reliability of bridge through the long-term monitoring measurements of strain sensors under traffic loads and researched the security limit using the actual traffic conditions and measurements of strain sensor on Wisconsin Rive Bridge in United States.

Key region is defined as the unfavorable region with higher stress level than the normal regions of the structure, which is related to the safety of the structure directly. Generally, the stress distribution of the key region is obtained by the measurements of limited sensors located on the key region directly, in which the stresses of elements without sensors locating on can not be obtained. In addition, it is impossible to measure the stresses of all the elements in the key region due to the requirements in economic and the construction of the structural health monitoring system. Therefore, the stress identification method based on measurements of limited strain sensors is proposed.

In the structural health monitoring system of Shenzhen Citizen Center in China, the stress fields of brace steel brackets are identified by the limited

Corresponding author: Jun Teng, PhD, professor, research field: structural health monitoring. E-mail: tengj@hit.edu.cn.

measurements of strain sensors located on the key points [7]. However, the measurements of strain sensors located on the normal regions should also be used to obtain the stress distribution identification of the key region, which can provide much more known measurements and reduce the incompleteness of information existing in structural health monitoring system. Information fusion technique can fuse the measurements of strain sensors located on key region and the normal regions, and give synthesized information for identification, eliminate redundancy and contradictions that may exist. Information fusion technique has been used in structural damage identification, while it is demonstrated that the identification results are better than that only using one sensor information source by numerical examples [8, 9].

The objective of the research is to develop a stress identification method using fuzzy pattern recognition and information fusion technique, while the acquisition for the stress distribution of the key region is discussed using the measurements of strain sensors located on both the key region and the normal regions. Correspondingly speaking, the acquisition for the stress distribution of the key region using measurements of strain sensors located on the key region is called the key region identification; and the acquisition for the stress distribution of the key region using measurements of strain sensors located on the normal regions is called the normal region identification. Firstly, the key region identification and the normal region identification are obtained by the fuzzy pattern recognition; secondly, information fusion technique is used to give the synthesized stress distribution of the key region; finally, the stress distribution identification for a shell structure is simulated and the method is proofed to be effective.

2. Basic Process

The proposed method is divided into early-stage preparation part and real-time monitoring part, which is shown in Fig. 1. In the early-stage preparation part, firstly, the key region identification and the normal region identification are obtained using fuzzy pattern recognition; secondly, the selected normal region identification results are decided using the D-S evidence theory; thirdly, the different fusion coefficients for the key region identification and the selected normal identification are assigned using the

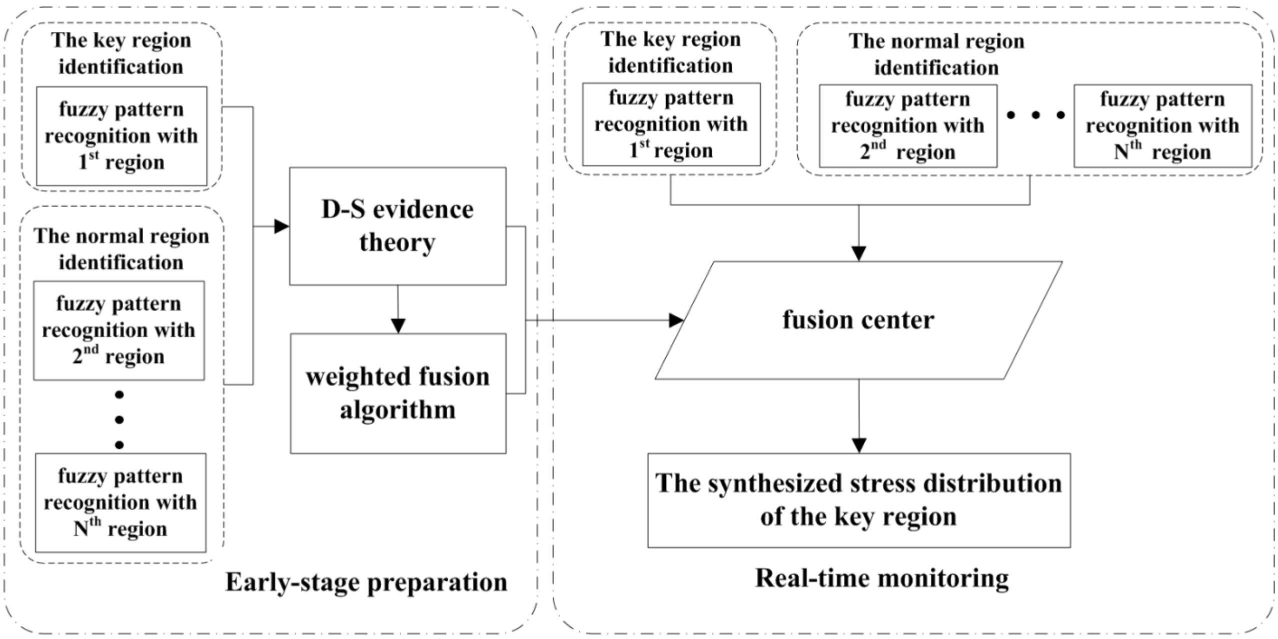

Fig. 1 The framework of the stress identification method.

weighted fusion algorithm; finally, all the results are saved in the fusion center for obtaining the synthesized stress distribution of the key region in real-time. In the real-time monitoring part, firstly, the key region identification and the normal region identification are acquired using fuzzy pattern recognition; secondly, the synthesized stress distribution of the key region can be obtained with different fusion coefficients.

3. Fuzzy Pattern Recognition

The pattern recognition aims to classify the new pattern into some pattern in the standard pattern library based on a priori knowledge, in which the feature vector is extracted to represent the characteristics of the pattern and the fuzzy neartude is used to measure the similarity between new pattern and some pattern in the standard pattern library. To represent the global characteristics of the feature vectors, the fuzzy set constructed by the membership function of each element in feature vector is used to calculate the fuzzy neartude between patterns.

In the paper, the feature vectors of pattern recognition can be obtained by the measurements of strain sensors located on the key region and the normal regions. The standard pattern library is formed by calculating the different stress distributions of the key regions under different load cases in the finite element analysis, while the domain U of fuzzy pattern recognition is formed by the feature vectors under different load cases. In order to reflect the characteristics of the stress distributions of the key region better, the variation of stresses in measured elements should be sensitive to the change of load cases, so the elements with larger means and variation coefficients in stress distributions are selected to located sensors on.

3.1 Membership Function

The i^{th} pattern in the standard pattern library, the feature vector can be denoted as:

$$\sigma^i = \left[\sigma_1^i, \sigma_2^i, \cdots, \sigma_n^i\right] \tag{1}$$

The membership function of the stress in the j^{th} measured element in the feature vector can be expressed as [7]:

$$\mu_j^i = \frac{\sigma_j^i - \sigma_{j\min}^i}{\sigma_{j\max}^i - \sigma_{j\min}^i} \qquad j = 1, 2, \cdots, n \tag{2}$$

where, σ_j represents the stress of the j^{th} measured element of the i^{th} pattern, σ_{jmax} and σ_{jmin} are the maximum and minimum stresses of the j^{th} measured element in the domain *U*. In this way, corresponding with domain *U*, the fuzzy subset A_i of the i^{th} patter is:

$$A_i = \left[\mu_1, \mu_2, \cdots, \mu_n\right] \tag{3}$$

The standard pattern library is composed of m patterns, whose fuzzy set is denoted as *A*,

$$A = \{A_1, A_2, \cdots, A_m\} \tag{4}$$

And the fuzzy set *B* to be recognized can also be calculated in the same way. If B is close to A_i, then *B* is classified into A_i.

3.2 The Principle of Classification

The fuzzy neartude which can measure the nearness of two fuzzy subsets is denoted as [10]:

$$D(A_i, B) = \frac{2\sum_{j=1}^{n} \min(\mu_{A_i}(x_j), \mu_B(x_j))}{\sum_{j=1}^{n} \mu_{A_i}(x_j) + \sum_{j=1}^{n} \mu_B(x_j)} \tag{5}$$

where, $B(\mu_j)$ represents the membership function of the stress in the j^{th} measured elements in the pattern to be recognized. The fuzzy neartudes of fuzzy subsets between the pattern to be recognized and the patterns in the standard pattern library can be acquired by Eq. (5).

In the original fuzzy pattern recognition method, the pattern of stress distribution to be recognized is classified into some pattern with the largest fuzzy neartude in the standard pattern library, that is to say, the stress distribution of the key region is the stress distribution of the pattern with the largest fuzzy neartude. However, the differences among the first few patterns with larger fuzzy neartudes are very small, that is to say, such patterns in the library can also represent a certain feature of the pattern to be recognized. Therefore, in the paper, the first few patterns with larger fuzzy neartudes are considered to decide the weighting coefficients for classifying the new pattern, while an improved method is proposed and the corresponding identified stress is known as:

$$\sigma_i' = \frac{\sum_{j=1}^{m} D_j \sigma_{ij}}{\sum_{j=1}^{m} D_j} \tag{6}$$

where, σ_i' is the stress identification result of the i^{th} measured element in the key region, D_j is the j^{th} largest fuzzy neartude, σ_{ij} is the stress of the i^{th} measured element in the pattern with j^{th} largest fuzzy neartude, m is the number of patterns which participate in the weighted average.

4. Information Fusion

4.1 D-S Evidence Theory

D-S evidence theory [11], a probability-based information fusion classification algorithm, is useful when the information sources contributing information cannot associate a 100 percent probability of certainty to their output decisions. The D-S evidence theory is used to select the normal region identification results which are applied to calculate the synthesized stress distribution of the key region.

The hypothesis space is made of a finite set of n mutually exclusive and exhaustive propositions, which is called the frame of discernment and denoted by Θ. A power set of 2^Θ is the set of all the subsets of Θ including itself and a null set Φ. Each subset is called a focal element. The basic probability assignment (BPA) is critical variable of evidence theory. The BPA of any subset A is represented as $m(A)$, which defines a mapping of 2^Θ to the interval between 0 and 1. The value 0 and 1 indicate no belief and total belief in a proposition separately, and any value between these two limits indicates different partial beliefs. Formally, the description of BPA can be represented as:

$$\begin{aligned} & m: 2^\Theta \rightarrow [0,1] \\ & m(\phi) = 0 \\ & \sum_{A \subseteq 2^\Theta} m(A) = 1 \end{aligned} \tag{7}$$

The assigned probability to Θ is considered as the amount of uncertainty within the BPA.

In the paper, the BPA is acquired by statistical evidence method [12]. If a group of evidence is acquired on the results of statistical test, then it is called statistical evidence. Statistical evidence is the usage of D-S evidence theory in statistical problems, which is a new method Shafer used to handle statistical problem, and is an attempt using non-statistical methods to solve statistical problem.

The observation of statistical testing is determined by a group of probability models $\{p_o | o \in \Theta\}$, in which Θ is the frame of discernment, p_o is the probability when the proposition o is given.

The frame of discernment is defined as {"accurate identification A", "inaccurate identification $\bar{A}$"} in the paper. When all the BPA cannot be assigned to $m(A)$ and $m(\bar{A})$, the rest of BPA is assigned to Θ, that is $m(\Theta)=m(A \cup \bar{A})$. The probability of accurate identification p_A is defined as the probability of the identification error less than 15%, which is acquired by analyzing the errors of stress distribution in the key region obtained by the measurements of sensors in the key region and the normal regions. Then, the BPA of Θ is calculated by the statistical evidence method listed as follows.

Assuming the consensus assumption is met, that is, $\Theta^0 = \{A, \bar{A}\}$ is an ordered set of Θ, which satisfies $p_A > p_{\bar{A}}$, then the corresponding BPA is

$$\begin{aligned} & m(A) = \frac{p_A - p_{\bar{A}}}{p_A} \\ & m(\bar{A}) = 0 \\ & m(\Theta) = \frac{p_{\bar{A}}}{p_A} \end{aligned} \tag{8}$$

If the consensus assumption can not be met, the generalization method of acquiring BPA can be achieved by weakening the consensus assumption.

That is, if $\Theta^0 = \{A, \bar{A}\}$ is an ordered set of Θ, which satisfies $p_A < p_{\bar{A}}$, then the corresponding BPA is

$$m(A) = p_A \\ m(\bar{A}) = p_{\bar{A}} \\ m(\Theta) = 0 \tag{9}$$

After calculating the BPA, the Dempster's rule is used to combine the information. The BPA of fusing the identification results obtained by the measurements of sensors in i^{th} and j^{th} regions are given by

$$m_{ij}(A) = K(m_i(A)m_j(A) + m_i(\Theta)m_j(A) + m_i(A)m_j(\Theta)) \\ m_{ij}(\bar{A}) = K(m_i(\bar{A})m_j(\bar{A}) + m_i(\Theta)m_j(\bar{A}) + m_i(\bar{A})m_j(\Theta)) \\ m_{ij}(\Theta) = Km_i(\Theta)m_j(\Theta) \tag{10}$$

Where, m_i and m_j are BPA of the identification results of the i^{th} and j^{th} regions.

$$K^{-1} = 1 - (m_i(A)m_j(\bar{A}) + m_i(\bar{A})m_j(A)) \tag{11}$$

When there are three or more stress distributions obtained by the measurements of sensors in the key regions and the normal regions, the application of Dempster's rule is repeated using the BPA calculated from the first application of the rule and the other BPA from another stress distribution. The Dempster's rule is used to fuse all the possible combination of the stress distributions obtained by measurements of the key regions and the other regions. Finally the combination which has the highest BPA for "accurate identification *A*" will be selected to calculate the synthesized stress distribution of the key region.

4.2 Weighted Fusion Algorithm

The weighted fusion algorithm is used to obtain different fusion coefficients for the key region identification and the normal region identification. If the identified stress of one element in the key region obtained by the measurements of sensors in n regions are $\sigma_1, \sigma_2, \cdots \sigma_n$, which are independent of each other, and the fusion coefficients corresponding to them are $w_1, w_2, \cdots, w_n$, then the synthesized results is defined as

$$\hat{\sigma} = \sum_{i=1}^{n} w_i \sigma_i \tag{12}$$

where, the fusion coefficients satisfy $\sum_{i=1}^{n} w_i = 1$.

The fusion coefficients *w* is determined on the purpose of minimizing the identification errors, which is calculated by minimizing the fitness function with genetic algorithm.

The fitness function is as follows:

$$f = \sqrt{\frac{\sum_{k=1}^{m} (e_{ki})^2}{m}} = \sqrt{\frac{\sum_{k=1}^{m} [(\tilde{\sigma}_i - \hat{\sigma}_i)/\tilde{\sigma}_i]^2}{m}} \tag{13}$$

where, *m* is the number of total identified stresses of the i^{th} elements in the key region with the training samples; $\tilde{\sigma}_i$ is the true value of i^{th} element stress; $\hat{\sigma}_i$ is the synthesized stress of i^{th} element acquired using information fusion, which is given by Eq. (12).

5. Numerical Simulations

5.1 The Finite Element Model

The model is a Schwedler-type single-layer sphere lattice shell as shown in Fig. 2.

The section of the elements in radial direction is 133 mm in diameter and 4 mm in thickness and the section of the elements in ring direction and in oblique direction is 127 mm in diameter and 3mm in thickness. The finite element model of the lattice shell consists

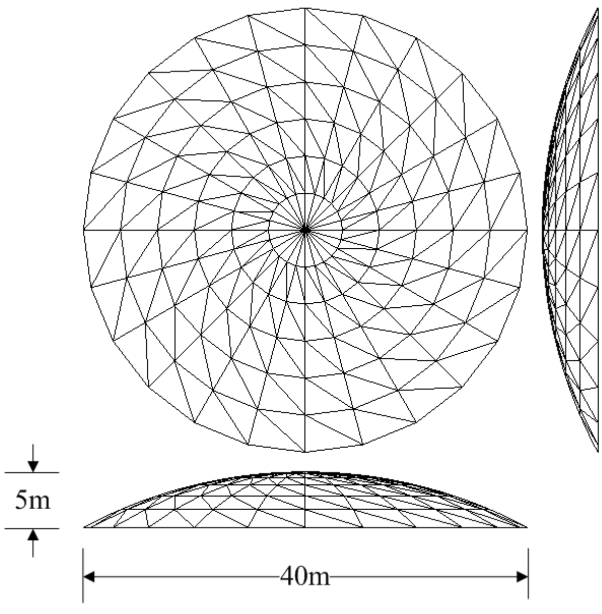

Fig. 2 The finite element model of the lattice shell.

of 145 nodes, 408 elements, and the supports are fixed supports. In the analysis, the distributed mass is 200 kg/m^2; Young's Modulus is $E = 2.06 \times 10^{11}$ N/m^2; the Poisson ratio is $\mu = 0.3$.

5.2 The Division of the Lattice Shell

The structure is divided into four regions according to the similarity and the region 1 with 30 elements in ring direction is selected to be the key region for stress identification, which is shown in Fig. 3.

5.3 The Selection of the Measured Elements

The measured elements are selected based on the larger means and variation coefficients in each ring of the structure are selected the measured elements, which are shown in Fig. 4 with light color. In addition, the dark colors in Fig. 4 are the unmeasured elements in the key region. Moreover, the measured elements in normal regions have the same arrangements as the key region.

5.4 The Establishment of Samples

In order to determine stress distribution patterns, wind loads are simulated with mean wind speeds from 5 m/s to 60 m/s, in every 5 m/s, a total of 12 different grades in wind loads. The simulation time of wind loads is 10 minutes and the sampling frequency is 10 Hz, so there are 6000 load steps in each grade of wind loads. There are 6000 patterns of stress distributions corresponding to each grade of wind loads from the finite element analysis.

The standard pattern library is formed of 2000 patterns of stress distributions under each grade of wind loads. The training set is formed of 50 patterns of stress distributions under each grade of wind load are extracted to form the training set. The patterns in standard pattern library and the training set are different. The testing set is formed of 50 patterns of stress distributions under the wind load with mean wind speed 42.5 m/s.

The relative error is used to evaluate the accuracy of the identification. Meanwhile, the elements with

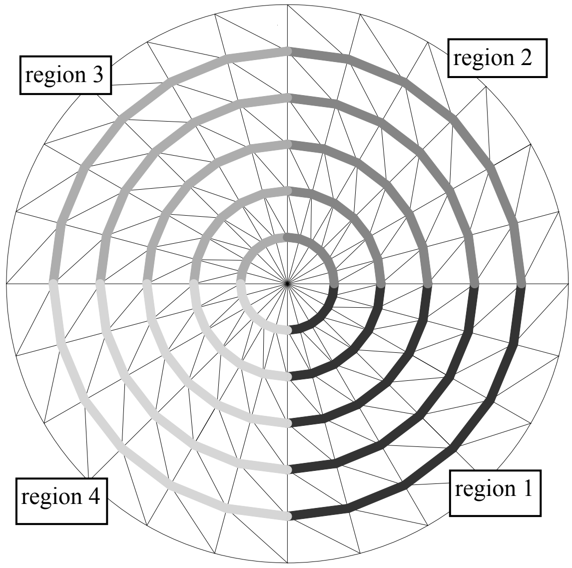

Fig. 3 The division of lattice shell.

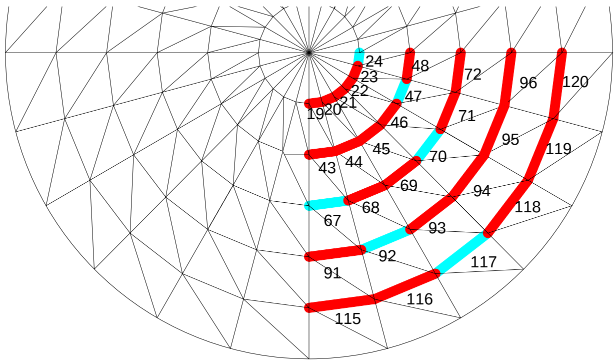

Fig. 4 The arrangement of key regions and measured elements.

large stress value are more important, so the effective of the method is assessed by the identification relative error of these elements. The identification results, in which the stress of the element is more than 100 Mpa, are considered to be used as assessment in the effective of the method, while there are 286 identification results.

5.5 The Key Region Identification

The identification results of the original method and the improved method using fuzzy neartude is compared and shown in Fig. 5. It can be seen that the number of cases with errors less than 5% using the improved method is larger than that using the original method and the improved method is much more accurate than the original method.

When the measurements are disturbed by noise level of 5%, 10%, 15% and 20%, which are defined as the ratio of the root mean square (RMS) of the noise to the RMS of stress time series, the identification results of improved method are shown in Fig. 6, the accuracy of identification results is not be affected obviously in the situation of low noise level. However, the accuracy under the disturbing of high noise level is decreased.

5.6 The Synthesized Stress Distribution of the Key Region

The corresponding regions for calculating the synthesized stress distribution of the key region is selected by D-S evidence theory and are shown in Table 1. The region in the Table 1 is the corresponding regions selected to calculate the synthesized stress value of the element in the key region.

The identification results without using information fusion is denoted as the identification results before information fusion; the identification results using information fusion is denoted as the identification results after information fusion, which are analyzed and shown in Fig. 7. The results show that the method using information fusion increases the accuracy of identification, but the effectiveness is not very obvious.

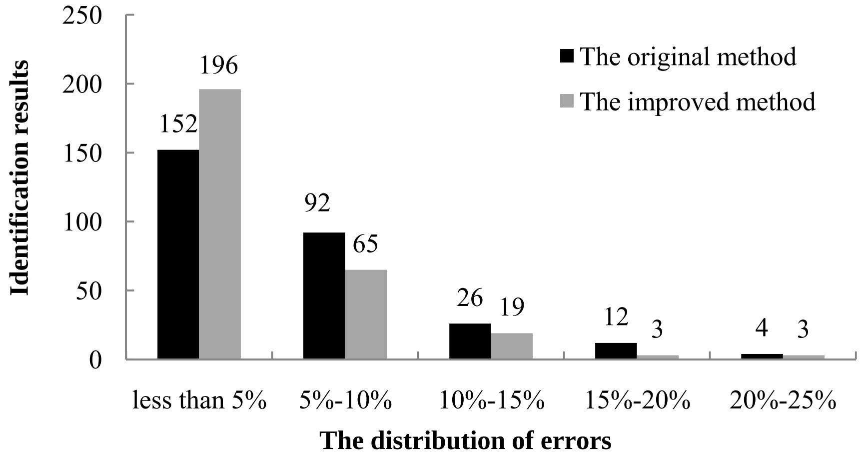

Fig. 5 The distribution of errors with fuzzy pattern recognition.

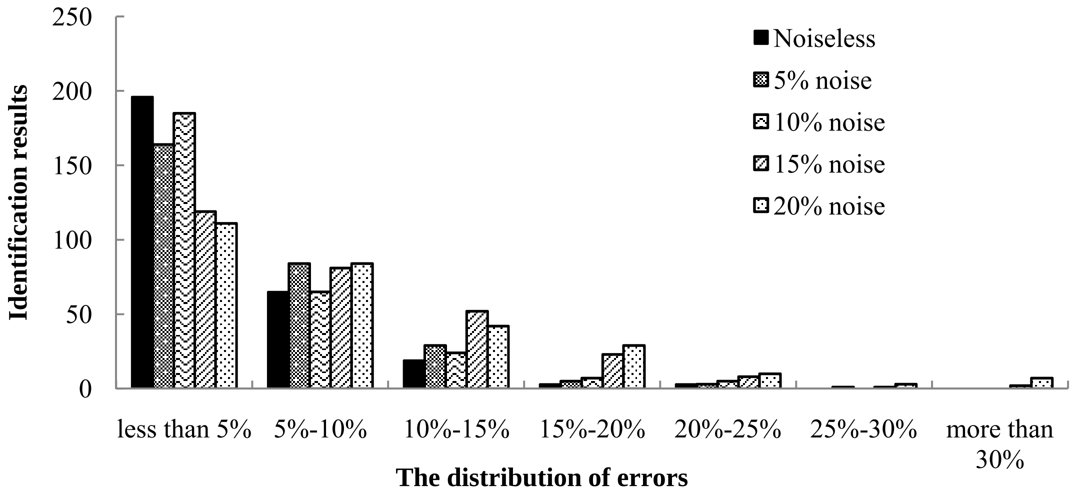

Fig. 6 The distribution of errors with noise.

When the measurements of sensors are disturbed by noise level of 5%, 10%, 15% and 20%, the identification results using information fusion technique are shown in Fig. 8. Comparing with the method without using the information fusion, the identification results are more accuracy under noise disturbing especially in the case of high noise level, as shown in Table 2. The results illustrate that the proposed method using information fusion technique is effective.

Table 1 The regions selected by D-S evidence theory.

element	region	element	region	element	region	element	region	element	region
19	1、4	43	1、2、4	67	1	91	1、2、4	115	1、2、4
20	1、2、4	44	1、2、3、4	68	1	92	1、2、4	116	1、2、4
21	1	45	1、2、4	69	1、2、4	93	1、2、4	117	1
22	1	46	1、2、4	70	1	94	1	118	1、2
23	1	47	1	71	1、2、4	95	1、2、4	119	1、2、4
24	1	48	1、2、4	72	1、2、4	96	1、2、4	120	1、2、4

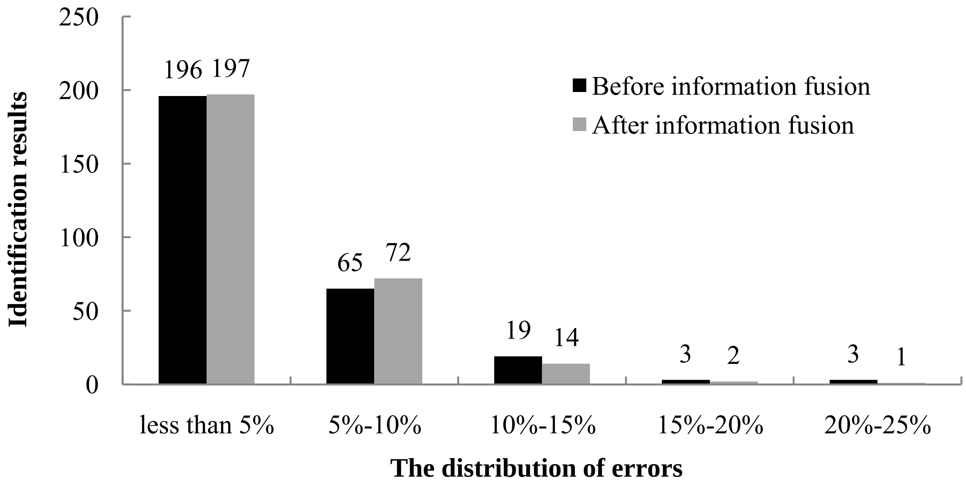

Fig. 7 The distribution of errors with information fusion.

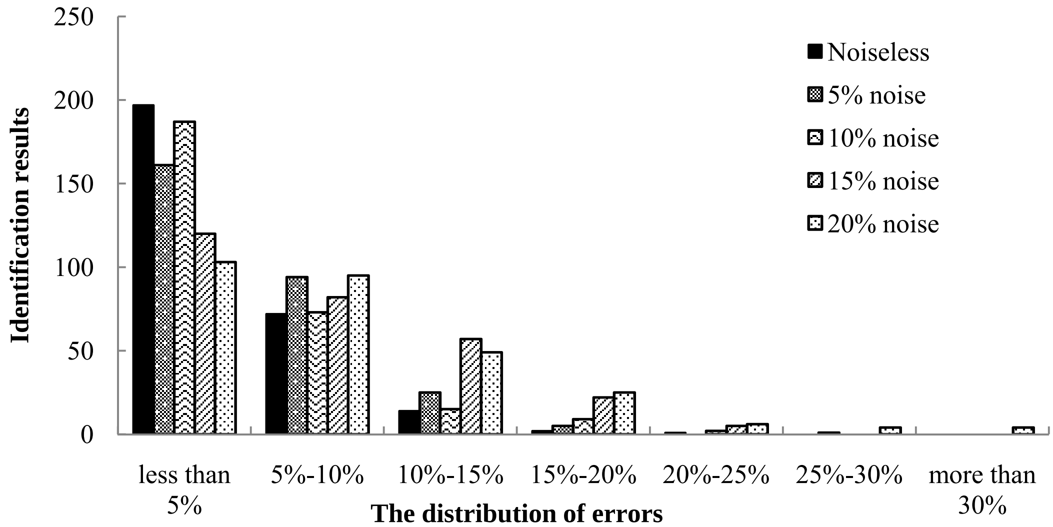

Fig. 8 The distribution of errors with noise.

Table 2 The comparison of identification results with noise.

Noise level	Before information fusion		After information fusion	
	The ratio of errors less than 15%	The maximum error	The ratio of errors less than 15%	The maximum error
0	97.90%	23.20%	98.95%	23.20%
5% noise	96.85%	25.16%	97.90%	25.15%
10% noise	95.80%	23.20%	96.15%	23.27%
15% noise	88.11%	33.60%	90.56%	23.88%
20% noise	82.87%	36.25%	86.36%	32.99%

5. Conclusions

The stress identification method using the measurements of sensors in the whole structure is proposed. An improved fuzzy pattern recognition method introducing the fuzzy neartudes as the weighting coefficients is discussed. The measurements of sensors in the normal regions are used to improve the accuracy of stress identification in the key region by information fusion technique. The following conclusions can be obtained:

(1) The original fuzzy pattern recognition can be used to identify stresses of elements with limited measurements of sensors, but the identification accuracy is not very good.

(2) The usage of improved fuzzy pattern recognition and information fusion technology can improve the reliability of stress identification.

(3) The D-S evidence theory is effective in selecting the normal region identification, and the weighted fusion algorithm can be used to acquire the fusion coefficients of each region. But these two methods could only be used in the early-stage preparation part with data from the finite element model.

(4) When the measurements of sensors are disturbed by noise, especially in the case of high noise level, the use of information fusion technique will bring in more reliable results.

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Static Requirement and Type's Complexity in the Diagnostics Phase

Antonella Guida and Antonello Pagliuca
Department of European and Mediterranean Culture: Architecture, Environment, Cultural Heritage (DICEM) - Matera, Italy

Abstract: The preservation of a historical building, whatever its architectural and/or artistic value, is more successful when undertaken with a deep understanding of the building's history, development, materials and construction techniques. The preliminary phase of any restoration intervention must start with data acquisition regarding the characteristics and conditions of the building, including a survey of significant alterations. In a great number of cases, restorations are not respectful of the building's static efficiency, so its static requirement is weakened. In fact, a very high percentage of instances in which a restoration effort results in building damage is attributable to such modification's indifference to the structural balance of a structure, as consolidated over time. This study focuses on the restoration intervention on two trilobate pillars that separate the central space from the presbytery in the Cathedral of Matera, located in southern Italy. Through the use of sonic tests - carried out despite the complexity of the shape of the building and constructive elements that characterize these pillars — it was possible to show the effectiveness of the implemented intervention, highlighting critical points and weaknesses. The research aims to show how — despite the complexity of some structural elements of a building — in-depth knowledge of a structure's structure and history is essential to for the success of restoration interventions, which are respectful of a building's type and material peculiarities.

Key words: Structural complexity, static requirements, refurbishment interventions, diagnosis phase, conservation.

1. Introduction

The preservation of a historical building, whatever its architectural or artistic value, is more effective when based on an in-depth understanding of the building's development, materials and constructive techniques.

In fact, the protection and conservation of heritage buildings entails varied and sometimes even alarming aspects; however, they help us to identify the commonly called "*architectural emergency*". This is essentially related to the size and the great number of cases to resolve and – together — to the limited availability of usable resources and experiences. So, it's necessary to optimize in a better way the limited finances and resources allocated to restoration efforts.

Faced with a degraded monument, the renovation designer must answer three main questions: "*if*" to perform a restoration, "*where*" to perform a restoration and "*how*" to perform a restoration.

To these questions it is possible to add another one that regarding the economic aspect: "*when*" to perform a restoration intervention [10].

In order to respond adequately to these questions, it is necessary to advance "*step by step*", through easily defined procedures: the identification of degradation, the determination of its causes, the assessment of residual safety and, finally, the appropariate intervention and definition of its execution method [8].

So the preliminary action is the research of all information about the monuments; this information is required to describe the structure and all the transformations that it has suffered; in this situation, it becomes essential to know the history of the building, from its construction until the last modification that it has undergone. In the first phase of data acquisition, the direct recognition of the building characteristics and the survey of the checked alteration, should be

Corresponding author: Antonella Guida, professor, research fields: building refurbishment, recovery and requalification. E-mail: antonella.guida@unibas.it.

complemented by research of design documentation and of events that have affected the structure during all its life cycle [9].

2. Shape's Complexity and Static Balance

The structural and static complexity of the historical building represent the more important characteristics of each monument. In fact, in the last years, the necessity to operate interventions of masonry structural reinforcement has become increasingly urgent, stimulating both by the objective requirements related to increased degradation of the monumental buildings and by a greater interest towards conservation theory.

The restoration criteria, in fact, impose severe restrictions on the possibility to realize a different intervention types but — at the same time — stimulate the choice of the suitable solutions.

Naturally, these solutions will seek in changes to realize to the main parameters that constitute the mechanical part of the structure (i.e., the geometry, material and loads) [12].

In fact, changes, modifications, partial demolition and reconstruction are quite frequent in a building‘s history, especially in a monumental building. A lot of monuments, in fact, have modified its shape and it's structural and functional organization in its life cycle, realizing — for example — of super elevation or addition part of construction, modifying the static distribution of the force, etc.; a very high percentage of building damages are attributable to these modifications are not always sufficiently respectful of a structural balances consolidated over the time.

These changes led to new structural stresses - not always proportionately allocated over the building structure — and very often they lead a new shape and aesthetical characteristics.

Thus, the geometry changes are surely the most effective (i.e., the increase of stiffness obtained with the increase of resistant section or by adding a constraint) [11].

The criterion for an intervention on the geometry was almost abandoned, although structurally good; the practice of complete replacement of degraded elements with other more or less *"similar"* to the original is realized very often, while frequently are offered — in parallel to existing structures — structures that are able to bear the load of the structure, in case of triggering the collapse.

It is considered, therefore, that the elaboration of a proposed consolidation intervention is essential to achieve different objectives that ensure the maximization of the monument respect.

These objectives are:

(1) to allow maximum persistence of the original material, limiting at minimum the transformations (demolition, replacement, etc.);

(2) to recognize the variable *"time"* as a positive sign that are able to add value to the building, which must be understood as a "*palimpsest*" on which are layered different elements;

(3) to use objective knowledge that are closely related to the building or specific pathological situation;

(4) to make decisions on the basis of technical assessments, supported by an in-depth knowledge and never based on historical, critical or aesthetic judgments;

(5) to realize recognizable and reversible interventions, in order to make possible in the time control, monitoring, additional maintenance (i.e., the introduction of new technologies or systems more effectively);

(6) to establish a correct maintenance program over time, not aimed at any replacements intervention at predetermined intervals, but based on observation of the phenomena, in order to prevent possible dangerous situations and slow down the aging process of the building.

3. The Case Study

This research focus upon the Cathedral of Matera — located in a little city in the southern part of Italy (Fig. 1), a massive architectural structure, built at the end of the XIII century. In *Apulian Romanesque* style, it keeps its formal and architectonic connotations almost unchanged outside, even though some interventions have substantially changed the inside style. It does not show any plain deterioration signs of its static structure, but it is plain a pathology outside.

The study focuses on the analysis of the restoration intervention on two trilobate pillars (Fig. 2) that separate the central space from the presbytery.

Using sonic tests — carried out despite the complexity of the shape of building structural and constructive elements that characterizes these pillars — it is possible to show the effectiveness of the implemented intervention, highlighting its critical points and its weaknesses [1].

In fact, with the sonic tests are measured and analyzed the characteristics of propagation of elastic waves inside the walls with the aim to understand the homogeneity of the structure, the changes of material properties caused by degradation, the structural defects — such as cavities or cracks — and the magnitude of the resistance of materials [2].

This test is carried out by measuring the time and speed of the wave that passes through the wall, a mechanical impulse generated by a transmitter and picked up by a receiver [3].

The speed of an elastic waves in a homogeneous, isotropic and perfectly elastic, is linked to the dynamic elastic modulus Ed, by the following relation:

$$E_d = v^2 \cdot d \cdot \frac{(1+\nu)(1-2\nu)}{(1-\nu)}$$

in which:

Ed = dynamic modulus in Pa

v = speed of the wave in ms-1

ν = Poisson modulus

d = density of the elements in kgm-3

The elastic wave loses energy in his propagate, and this is due to a decrease in the intensity related to the propagation law of the spherical type, while another decrease is the interface between the gap, where the

Fig. 1 The Matera Cathedral.

Fig. 2 The trilobate pillars.

energy is partly reflected and partly refracted [4, 5].

High speed — closely proportional to the elasticity modulus and to the strength of the element — and short term indicate a compact structure (i.e., single body masonry or multiple body well connected), while discontinuities, fractures, porous materials are considerably lower speed and consequently increases time.

The test was performed on the above said columns, identifying different directions (Figs. 3–5) — at different heights — in order to cover the largest part of the surface; these directions would also consider the different materials connections, related to the particular shape of the pillars. Certainly this complexity became an important element to evaluate in order to operate a correct and precise evaluation of the investigations project [7].

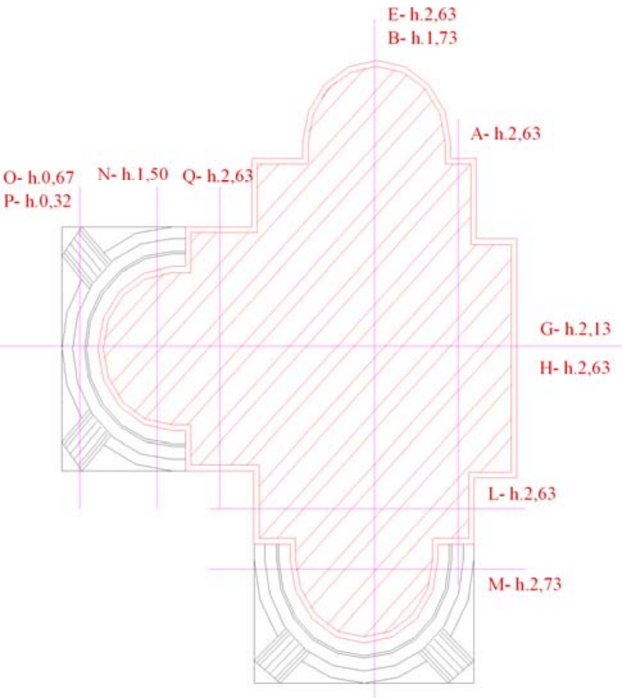

Fig. 3 Sonic directions of investigations carried out on the left trilobate pillar.

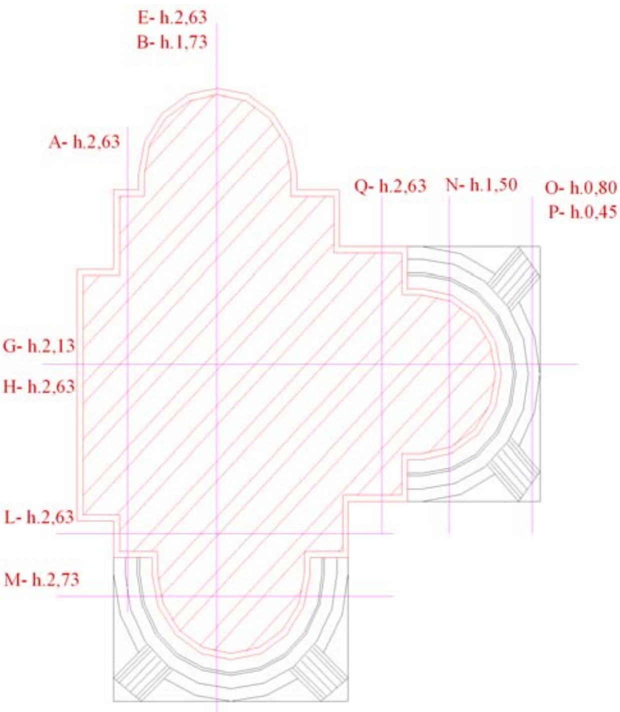

Fig.4 Sonic directions of investigations carried out on the right trilobate pillar.

Fig. 5 Damage visible on the surface of the pillars.

Tables 1–2 show, for each chosen investigation's directions, the values of average speed; in fact, they represent the average values of 12 speeds measured. In fact, were made 12 different measurements that returned 12 different values of propagation time of the wave and, consequently, 12 different values of propagation speed.

The sonic test carried out on the left pillar (Table 1) highlights the values between 1400 m/s and 1800 m/s at different levels and in the range 1.50–2.73, which usually characterize those walls not strongly degraded and presence of voids.

From the observation of results, it is possible to note that lower values are not recorded along the longest paths — such as those linking the two semi-columns or the semi-column with the pilaster — but along the shortest paths within the elliptical shape. This leads us to assume a more widespread damage, also visible on the surface of the pillars [6].

While, the investigations on the right pillar (Table 2) highlight of values between 1450 m/s and 1850 m/s at different levels and in the range 1.50–2.73, which usually characterize those walls not strongly degraded and presence of voids.

Table 1 Sonic tests results on the left trilobate pillar.

As			Bs									Es		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)							s(m)	t(us)	V(m/s)
1.57	942	1686.902	2.37	1315	1763.13							2.37	1374	1768.393
	916			1321									1285	
	944			1317									1295	
	921			1352									1281	
	947			1331									1345	
	933			1346									1332	
	922			1343									1340	
	909			1348									1376	
	922			1372									1345	
	941			1355									1363	
	983			1362									1361	
	919			1367									1362	
			Gs			Hs						Ls		
			s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)				s(m)	t(us)	V(m/s)
			1.87	1199	1598.837	1.87	1133	1823.145				0.95	613	1434.395
				1212			1002						634	
				1172			1023						628	
				1116			1017						691	
				1147			1020						639	
				1141			1036						644	
				1173			1025						661	
				1147			1039						692	
				1176			1051						668	
				1161			1027						676	
				1192			1016						692	
				1188			1003						690	
Ms			Ns			Os			Ps			Qs		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)
0.61	371	1474.142	0.58	448	1494.075	0.96	341	2785.839	0.96	391	2442.748	0.84	553	1372.998
	407			408			336			393			531	
	400			415			349			389			573	
	396			429			350			382			563	
	412			405			348			381			575	
	432			431			343			381			633	
	394			353			351			394			657	
	384			354			342			399			630	
	472			354			350			405			636	
	406			348			344			405			656	
	435			354			336			401			648	
	482			379			343			395			651	

Table 2 Sonic tests results on the right trilobate pillar.

Ad			Bd			Cd			Dd			Ed		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)							s(m)	t(us)	V(m/s)
1.49	886	1694.337	2.31	1572	1644.713	2.31		#DIV/01	2.31		#DIV/01	2.31	1260	1828.4
	871			1356									1287	
	855			1361									1257	
	879			1424									1300	
	899			1388									1240	
	848			1434									1243	
	894			1427									1019	
	863			1415									1251	
	883			1423									1249	
	870			1427									1271	
	894			1333									1284	
	922			1390									1292	
Fd			Gd			Hd			Id			Ld		
			s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)				s(m)	t(us)	V(m/s)
1		#DIV/01	1.81	1082	1750.822	1.81	1037	1883.259	1		#DIV/01	1	620	1477.541
				1002			957						664	
				1043			970						650	
				1046			956						670	
				1011			937						654	
				1011			960						683	
				1005			945						678	
				1005			947						724	
				989			980						689	
				1037			963						701	
				1096			966						709	
				1116			967						670	
Md			Nd			Od			Pd			Qd		
s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)	s(m)	t(us)	V(m/s)
0.67	452	1459.059	0.60	444	1440.23	0.98	394	2401.372	0.98	472	2164.789	0.83	474	1442.726
	422			434			393			452			521	
	488			440			434			436			560	
	461			416			422			433			546	
	411			416			412			472			552	
	436			408			407			436			543	
	485			402			416			407			667	
	466			415			403			472			648	
	459			410			418			440			565	
	452			418			400			452			623	
	471			402			406			462			594	
	496			407			403			536			601	

Even the pillar right, by the observation of partial results show that higher values are recorded along the longer trajectories (as above said), the lowest (about 1400 m/s) along the shortest paths within the elliptical shape. This leads us to do the same considerations of the left pillar.

Sonic tests were carried out also on the stone base of the pillars using the same investigation test. The measured values are greater than 2000 m/s that indicates a good state of preservation.

The research — applied on the above described pillars — is on going also for the other structural elements of the Matera Cathedral in order to provide a complete knowledge of the monument and to develop a suitable restoration intervention.

4. Conclusions

The research aims to show how — despite the type complexity of some structural elements of a building — becomes essential an appropriate building knowledge to realize interventions that are able to operate a correct restoration intervention of a building and, at the same time, which it is respectful of its type and material peculiarities.

The study aims to realize an applicative methodology more respectful of the monumental heritage, in order to avoid a simple critical transposition of the calculation models in the recovery interventions.

This research can also contribute to increment the typology of the tests to carry out on the masonry; in fact, in relation to all the problems of tests and investigations (first of all the geometrical complexity), it is not necessary to have only one kind of survey, but an organic plan that consider in particular way the shape and the morphology of the investigated element, in order to have a more possible complete cognitive frame. Only in this way it is possible to interpret the real phenomena and give the necessary parameters to realize a correct intervention.

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Characteristics of User Redesign Process: A Study of Changes Made by Users in Architect-Designed Housing

Nghai Ezekiel Suleman

Department of Architectural Technology, Federal Polytechnic, Kaura Namoda, Zamfara State, Nigeria

Abstract: Housing is dynamic. It changes with time. A sample of 60 houses in the Shagari Low Cost housing scheme in Kaura Namoda was studied in order to find out the characteristics of changes made by the users. Physical observations and questionnaires were used as the major instruments of data collection. The results show that 91% of occupants have made various changes to the original designs without the help of professional designers, and some of the changes have completely transformed the outlook of the houses in locational planning, materials and form. This implies that a post architectural design phase exists, suggesting that the design process can be divided into two phases; the initial design by the architect and the subsequent redesign by the user. The paper presents preliminary findings on the general characteristics of user redesign and concludes that a clear process can be established. The architectural design process can, therefore, be expanded to include the user redesign process in order to reflect the entire lifespan of the building.

Key words: Architectural design process, changes, expanded design process, housing, user redesign.

1. Introduction

Built environments have great potentials for change. Change induced by dwellers is necessary at all levels for a healthy, vital steadily improving environment Habraken [1]. Brand [2] discusses how various types of buildings change, concluding that institutional buildings are the most resistant to change, commercial buildings change kaleidoscopically while domestic buildings are the steadiest changers as they have to respond daily to the interaction of man and the house.

Housing environments change constantly owing to a number of factors which include changing family size and structure, changing tastes, development of new technology, fashion, and so on. Habraken [1] explains that housing has great potentials for change and that this fact is a major factor that architects should consider in the design of housing. He calls on designers not to see housing as a finished product like with the rest of architectural artefacts but to consider the process of change. The right attitude in design of housing should be - one cannot finish things; one can only make them possible. Similarly, Granath [3] calls on architects to design architecture in such a way that it supports participation in the use of architecture. Architecture, especially housing, should be responsive to changes.

Users modify their housing environments consistently. These changes often distort the original intentions of the architect. Changes by users are therefore significant in defining the housing design process. Therefore, the architect’s inability to eventually predict user needs that are not clearly stated and the changing tastes of the user have often culminated in changes in the design during occupation. Boudon [4] studied Le Corbusier’s Quartiers Modernes Fruges, a rental housing scheme built in Pessac in 1926, and discovered that the occupants changed the character of the initial designs in order to express their personality. This study points to the fact that no matter how creative a designer may be, his designs could undergo changes by the users if they are not involved in the design process. The involvement of the user in changing the original designs is a part played by the user that has been overlooked but that is significant to the design process.

Corresponding author: Nghai Ezekiel Suleman, MSc (Architecture), research field: housing design process. E-mail: nghaisule@yahoo.com.

The focus of this paper, therefore, is to study the general characteristic of changes made by a sample of users of the Shagari Low Cost housing scheme in Kaura Namoda, Zamfara State, Nigeria and therefore attempt to chart the processes that produced the changes as having a distinct characteristic and to place it on an expanded architectural design process proposed by Suleman [5].

2. Background of Study Area

The study was conducted at the Shagari low cost housing scheme in Kaura Namoda. The Shagari Lowcost housing schemes were built all over the country in the early1980s and were meant to house the low income population. The design is basically a one bedroom core house with a toilet and bath and a kitchenette (see Fig. 1). The major concept was to produce an initial minimal space that could be expanded incrementally by the user.

The Shagari low cost at Kaura Namoda is located at the north western part of the town, off the Kaura Namoda - Shinkafi road. It consists of 100 housing units. In the 1980s when the Shagari low-cost housing was constructed, it was widely rejected throughout the country based mainly on location, insufficiency of space and lack of basic infrastructure. In Kaura Namoda the houses were rejected and were finally offered to the Federal Polytechnic which also rejected them. They were therefore sold to individuals. In the 1990s when increase in population of the polytechnic brought acute shortage of staff housing, the polytechnic had to acquire most of the housing units in the Shagari estate at exorbitant rates and turned them into staff quarters on affordable rents.

3. Methodology

For the study to be meaningful, various types of data needed to be generated; data establishing that significant changes occur in houses designed by architects, data showing the general process of user redesign, and data from which a general process of user redesign can emerge. Therefore, different data collection methods were used including physical observations, questionnaires, interviews and protocol analysis.

The initial plan was to show that changes do significantly occur in housing designed by architects. As a result physical observations were thought of as the most appropriate way to study changes made by occupants to architect-designed houses. Observed changes were documented through notes, sketches and photographs and measured drawings. An aspect of physical observation recommended by Zeisel [6] and which is central to this study is observing adaptive traces. “Adaptive traces are significant for designers because they are direct manifestations of design by

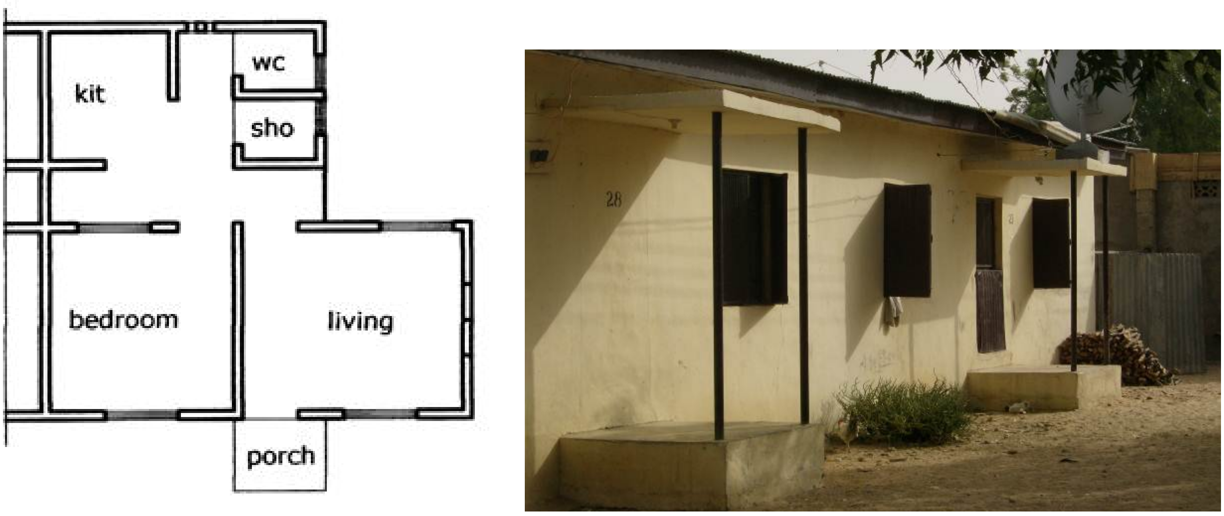

Fig. 1 Original plan and view of house.

users” Zeisel [6]. Visual data were used mainly to prove that users do effect changes in housing, and that the changes are significant as they affect all aspects of the building. Questionnaires were also administered to occupants to find the condition of their housing at occupation and the current state. The questionnaires also focussed on the process of change. A random sample of 60 houses, representing 60% of the houses, was chosen for the study. Some few houses were chosen purposefully to record the details of the changes that had been effected by the users.

Interviews were also conducted with occupants specifically on the process of change they adopted. The unstructured method of retrospective protocol analysis was adopted. Retrospective protocols of selected users were taken using a tape recorder and these were later transcribed and coded and finally compared to the three stages of the architectural design process — analysis, synthesis and evaluation — in order to establish the process the users applied.

4. Results

Preliminary results from physical observations and questionnaires are presented in this section.

4.1 Physical Observations

Observations showed that a lot of changes have occurred in the estate. Despite this the estate has maintained its general outlook except for few houses where the complete outlook of the house has been changed. Changes were dominated by changes of functions of spaces, and increase in room sizes which affected the structure of the building. Decoration was also affected as people changed finishes applied to the houses. Owing to the lack of pipe borne water in the estate, toilets, bathrooms and kitchens were generally relocated outside the houses. Figs. 2–8 show various modifications of the original plans.

Fig. 2 shows the original plan converted to a 3-bedroom house with the living room and bedroom retained while other facilities are relocated with additions made. The conversion changed the entire outlook of the house. Window hoods were added for sun shading. Fig. 3 shows the house converted to 3 bedrooms with a shop. This has also affected the front view. Fig. 4 shows addition of a high fence and gate, while Figs. 5–8 show different configurations of 2-bedroom options as effected by various users.

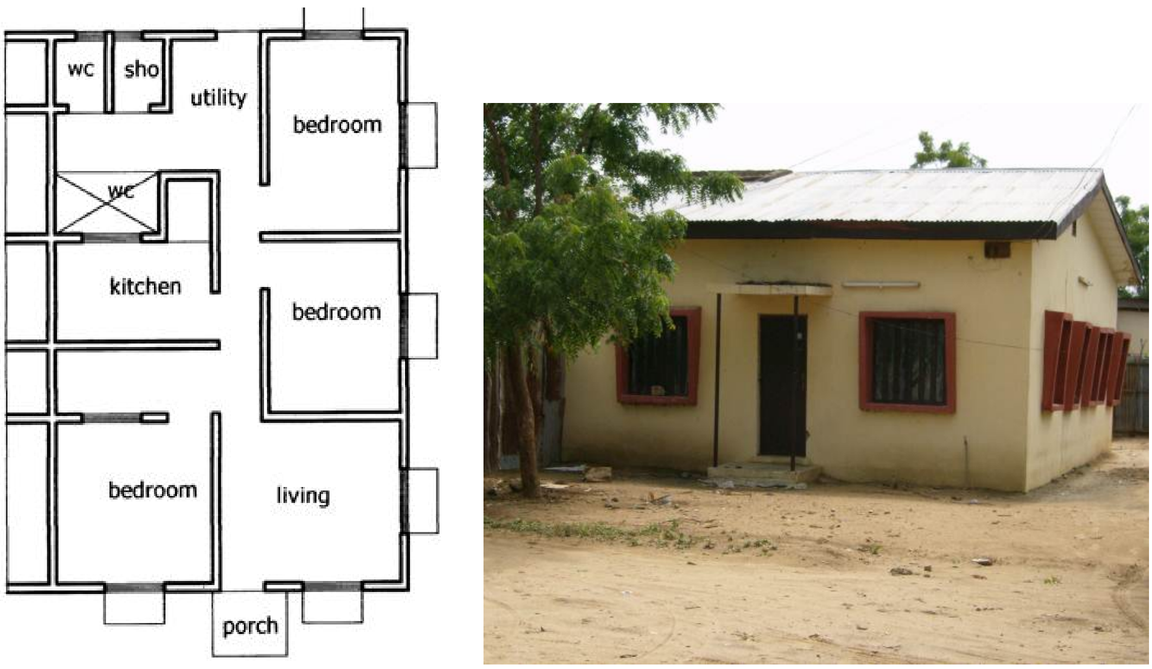

Fig. 2 Plan and view of redesigned house converted to 3 bedrooms.

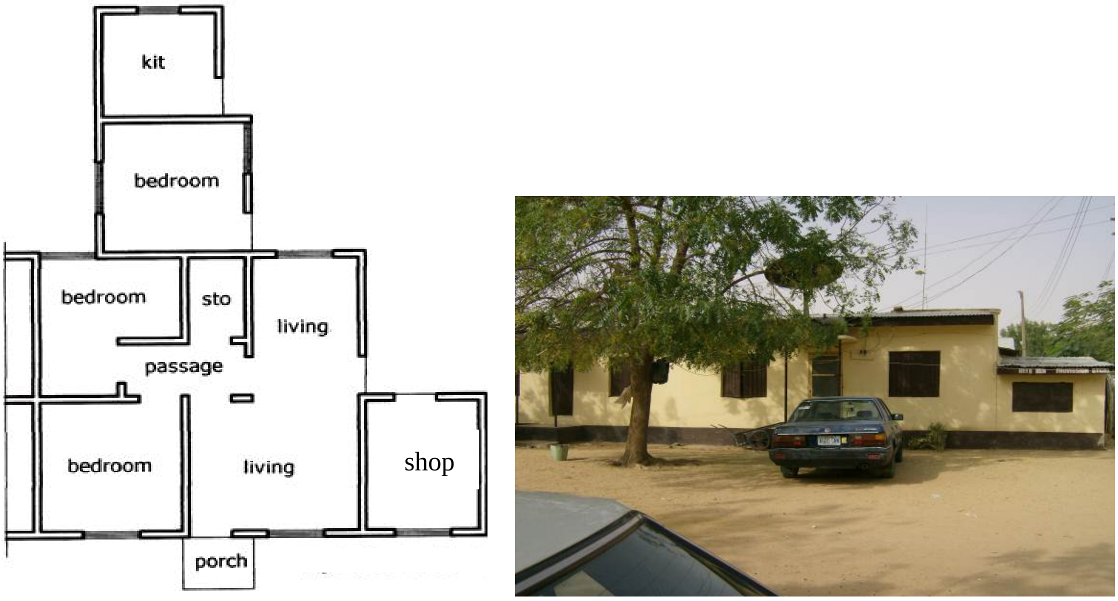

Fig. 3 Plan and view of redesigned house with shop addition.

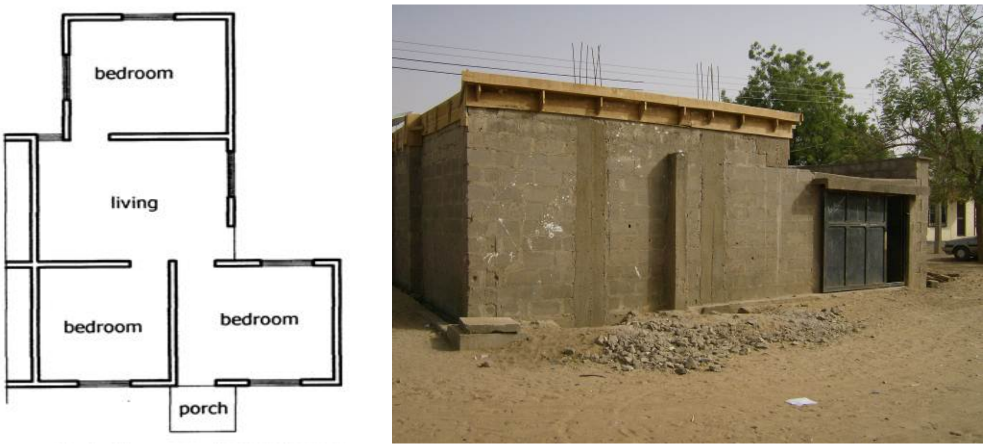

Fig. 4 Plan and view of redesigned house converted to 3 bedrooms with high fence wall and gate.

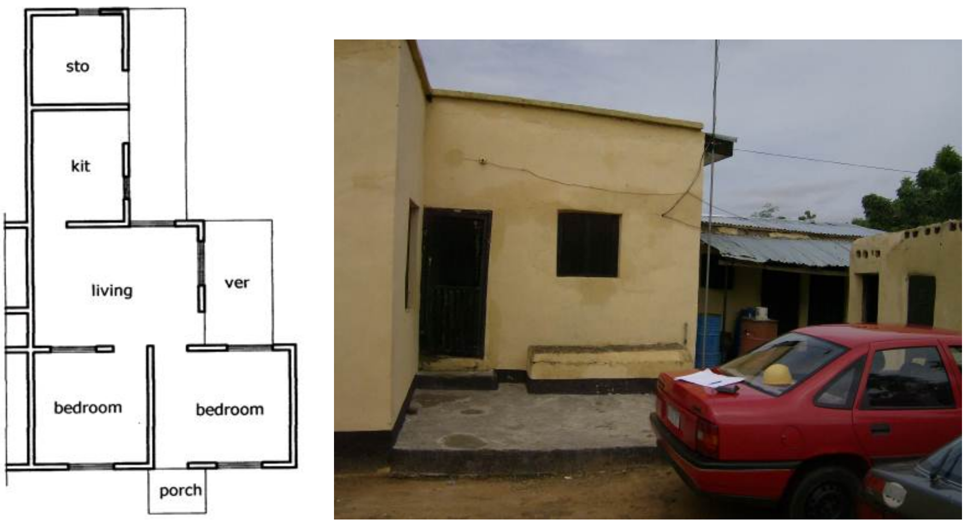

Fig. 5 Plan and view of house converted to 2 bedrooms.

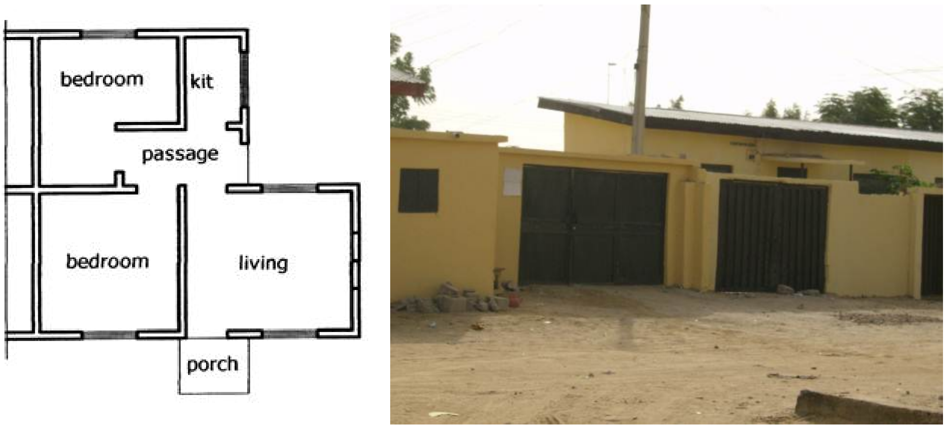

Fig. 6 Plan and view of house converted to 2-bedrooms with fence and gatehouse.

Fig. 7 Plan of house converted to 2-bedrooms.

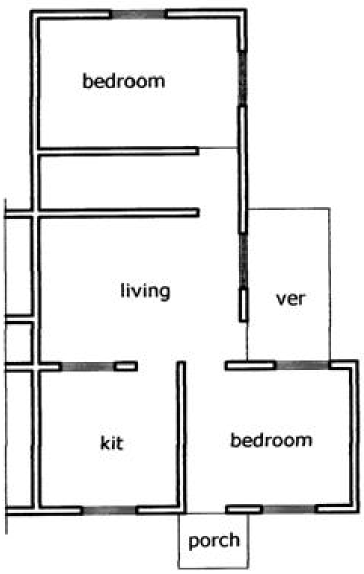

Fig. 8 Plan of house converted to 2-bedrooms.

These changes are significant as some of the houses have completely been changed beyond their initial outlook, showing that user redesigns are part of the development of the house. They cannot therefore be ignored; they form part of the design process.

4.2 Questionnaires

Of the 60 questionnaires distributed, 48 representing 80% were returned. From the questionnaires, it was discovered that 91% of respondents had made changes to the original design and the 9% that were yet to make changes indicated plans to make changes in the near future. Detailed findings from the questionnaires are presented in Tables 1–5 below.

Table 1 Types of changes.

Type of Change	Percentage
Increase in number of rooms	55
Size of spaces	15
Change affecting form	9
Changes affecting materials/finishes	11

Table 2 Sources of redesign ideas.

Source	Percentage
Intuition	29
Experience from lived-in problems	49
Suggestions from laymen (family, friends, etc)	7
Assistance of professional	15

Table 3 Constraints encountered.

Type of Constraint	Percentage
Cost	77
Technical competence	11
Plot size	10
Availability of materials	2

Table 4 Factors that caused changes.

Factor	Percentage
Seeking solution to problems	29
Increase in family size	49
Change of taste	20
Change in economic status	2

Table 5 Major Areas Affected by Changes.

Area	Percentage
Bedrooms	47
Kitchens	22
Store	14
Toilets	11
Living Room	3
Others (eg addition of shop)	3

5. Characteristics of User Redesigns

From the physical observations and questionnaire the following deductions were made:

5.1 Change in Housing is Inevitable

Item 2 in Table 6 shows that a total of 91% of the houses have undergone various changes that have completely affected the original designs. Changes affected the function of spaces away from what was originally planned by the architect. It cannot therefore be said to be the same building; it has been redesigned by the occupant. This implies that changes are inevitable in occupied houses and are a very significant part of the design process. This is instructive to designers; rather than looking at houses as static objects, designers should view them as dynamic. This view is consistent with that expressed in Habraken [1], calling on designers of housing not to see it as a final product but consider the possibility of future change.

Table 6 Some parameters that affected changes.

S/No	Parameter	% Yes	% No
1	Involvement in original design	0	100
2	Made changes to original design	91	9
3	Redesign was affected by initial design	68	32
4	Professional assistance in design	4	96
5	Affected by similar changes by neighbours	89	11
6	Produced alternative solutions	20	80
7	Used professional builders	32	68
8	Complete demolition	0	100
9	Communication of changes through sketch	12	88
10	Need for training of users in basics of design	85	15

5.2 Changes affect All Aspects of Design

Architectural design concentrates mainly on three aspects; function, form (structure), and aesthetics. The survey discovered that all these aspects of design were affected. Though most changes were functional, there were also changes in structure caused by addition of rooms and changing of roof structure. Aesthetics is affected by changes in finishes and painting and creation of new forms. Figs. 2–8 show the various changes in plan and form.

5.3 No Professional Assistance in Redesign

Most of the respondents indicated they did not consult any professional in the redesign of their houses. Item 3 in Table 6 shows that only 4% of respondents got professional advice. This indicates that the redesigns were made by the users themselves thus using the architect's initial design as a starting point for their designs. Producing their designs without the help of professionals is also significant. It brings out the creativity of the user in solving the problem "created" by the architect. The redesign by the user is part of the evolution of the building and should form part of the entire design process.

5.4 Hands-on (Trial-and-Error) Approach

Item 9, Table 6 shows that only 22% of respondents communicated their ideas through sketches, while 88% did not use sketches. This is a major difference between the architect's design and the redesign of the user. Unlike the architect who uses drawings and sketches, user redesigns are mental unaccompanied by sketches. Most of the changes are made on site as the builders work. Mistakes are corrected as observed (trial-and-error). This is usually costly as it implies undoing some of the work through demolition and reconstruction. Table 3 shows that the major constraint faced by occupants is cost (77%). This is likely because of such trial and error approach. Lack of sketches also affects evaluation. Ideas on paper can more likely be easily understood and criticised than mental ideas. Sketches are very useful in design as they help “reflective criticism” Lawson [7]. One major importance of sketching in the design process is that it serves as external memory and reduces the load on internal memory of the designer and thus helps the designer to recall easily by looking through the sketch Suwa et al. [8].

5.5 Problem-Driven Design Approach

Architectural designs are intuitive problem-solving processes. Ideas for user redesign stem mainly from experience of problems with the design. 49% of respondents affirmed this while 29% got ideas by intuition, 7% got ideas from other laymen and 15% from professionals (Table 2). Item 6 in Table 6 shows that only 20% of respondents produced alternative solutions, while 80% did not produce alternative solutions. User redesigns are therefore “problem-driven” while that of the architect is regarded as ‘solution driven’. Problem driven designs are seen as design in which “the designer focuses closely on the problem at hand and only uses information and knowledge that is strictly needed to solve the problem. The emphasis lies on defining the problem, and finding a solution as soon as possible”, and solution-driven design as designs in which “the designer focuses on generating solutions, and only gathers information that is needed to further develop a solution. The emphasis lies on generating solutions, and little time is spent on defining the problem, which may be reframed to suit an emerging solution.” [9].

5.6 Users not Involved in Original Designs

Item 1 in Table 6 shows that none of the users was involved in the design of the house occupied. In fact, none had knowledge of the designer. Architects have been criticised for designing without involving the users and calls have been made for the involvement of users in the design of their houses [6, 10–14],.

5.7 Changes Caused by Needs

Increase in family size was the major reason advanced for the need for changes by 49% of the respondents, while 29% of changes were caused by need to solve some problems. Other reasons are change in taste (20%) and change in economic status (2%) (Table 4). This is further confirmed by the dominance of addition of rooms as the major type of change (47%) as may be seen in Table 5. This further affirms that as long as changes in taste occur due to changes in status and family size for example, the house cannot remain static; it must change with changing tastes.

5.8 Direction of Changes Affected by Original Designs

Item 3 in Table 6 shows that 68% of respondents agree that the direction the changes took was detected by the original designs. 32% felt the original designs had nothing to do with changes made. This is instructive to architects to realise they need to make allowance in their designs for future changes. It also calls for studies to identify likely direction of user redesigns to help the architect make his initial design flexible to accommodate the anticipated future changes.

6. Inferences from Characteristics of Changes

From the study, the general process user redesigns take is as follows:

(1) Experience lived-in problems from architect-designed house

(2) Analyse problems

(3) Form mental picture of required changes

(5) Input from friends and family

(6) Effect changes

A clearly well-defined process of user redesign is similar to that of the architect. It is necessary to note that because the user has lived long with the problem, it is well-defined; he knows clearly what he wants. Solving well-defined problems, such as mathematics, tends to be linear. It is possible therefore that the user redesign process, unlike the cyclical design process of the architect, could be linear. Staying with the problem for long means there has been some synthesis before the solution could have been derived, however, lack of procedural knowledge and absence of sketching have limited the ability to synthesise. The synthesis stage appears not well developed but forms part of the problem analysis. Lack of alternative solutions completely eliminates the evaluation stage. It is possible to conclude tentatively therefore that user redesign process is a linear process composed of a strong analysis and a weak synthesis that are fused together producing a final solution. Further analysis through retrospective protocols will be helpful in clearly defining the process of user redesign.

7. Conclusion

The study has shown that changes in buildings are inevitable. Users make changes on designs initially made by the architect to meet their changing tastes. These changes often result in complete transformation of the initial model created by the architect into something completely different. Changes made by the user are often independent of the architect. This process of user redesign has its own distinct characteristics from that of the architect. This shows that the input of the user is very significant and should be reflected in the design process to cover the entire lifespan of the building. The study points to a possible two-staged design process; the first stage by the architect that has been found from studies to be cyclical, leading to the ‘final product’, and the second stage of user redesign which uses the architects ‘final product’ as its starting point to create a final solution. This calls for further research, for example, using retrospective protocol analysis, to plot an acceptable process of user redesigns, and finally incorporating the resulting user redesign process in the architectural design process to produce a comprehensive design process that would reflect the entire lifespan of the building.

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Irradiation Damage of Nano-C_2S Particles Studied by In-Situ Transmission Electron Microscopy

Hongfang Sun[1], Mahir Dham[2], Eric A. Stach[1] and Carol Handwerker[1]
1. School of Materials Engineering and Birck Nanotechnology Center, Purdue University, West Lafayette, IN 47907, USA
2. Mapei Corp., Deerfield Beach, FL 33442, USA

Abstract: Development of a reactive nanocement is a new approach to improve the physical and chemical properties of construction materials. However, due to the decreased size of cement particles, beam damage during transmission electron microscope (TEM) observation becomes more severe than in conventional cement. In this work, irradiation damage to nano-C_2S (dicalcium silicate) is observed and studied by in-situ evolution of diffraction patterns (DP), high resolution TEM (HRTEM), and electron energy-loss spectroscopy (EELS). The results show that the damage to nano-C_2S occurs through a decomposition reaction. Nano-C_2S is first amorphized, and then re-crystallized into CaO nano-crystals with average size of 7 nm surrounded by an amorphous matrix of Si and SiO_2. During this process, C_2S particles exhibit volume shrinkage. The damage energy causing the reaction was analyzed and electron-electron inelastic scattering produced radiolysis and heat, leading to the observed phenomena.

Key words: Nanocement, TEM, damage, inelastic scattering, decomposition.

1. Introduction

Cement is a mixture comprised of different components, i.e., C_3S, C_2S, C_3A, and C_4AF (where C = CaO, S = SiO_2, A = Al_2O_3, F = Fe_2O_3), among which dicalcium silicate (C_2S) is one of the major components. However, due to its slow hydrating nature, C_2S is usually used to provide long-term durability of concrete, and its early strength is mostly dependent on other minerals, such as C_3S and C_3A. A need to obtain a reactive form of C_2S mineral is based on this consideration. By improving its reactivity, C_2S may participate in early strength evolution and has the potential to improve medium term hydration as well. The development of nanocement [2, 7, 8] brings focus to this goal. An early age reactivity could be increased tenfold through exposing much more reacting surface area compared with conventional cements [8]. Based on this idea, nano-sized C_2S was therefore fabricated through a chemical combustion method. To understand the hydration properties of nano-C_2S, the precursor powder must first be well characterized. Transmission electron microscopy (TEM) is a commonly used tool for characterization of nanoparticles. However, with TEM we have to assess the extent of irradiation damage caused by the electron beam to electrically-insulating cement specimens [6, 9, 10]. In this work, beam damage of nano-C_2S particles was characterized during TEM observation and methods to reduce the damage are proposed.

Corresponding author: Carol Handwerker, professor, research fields: develop and apply thermodynamic and kinetic theory and experiments of phase transformations and interface motion to solve important industrial and scientific problems. E-mail: handwerker@purdue.edu.

2. Experimental

Nano-C_2S was synthesized from limestone and other naturally occurring materials by NanoDynamics (www.nanodynamics.com), using a chemical combustion reaction that is initiated at approximately 300°C versus the 1500°C used in the preparation of conventional cement. The microstructure and phases of the nano-C_2S were characterized by scanning electron microscopy (SEM, FEI Quanta 3D dual-beam system), X-ray diffraction (XRD, Bruker D8 instrument), and the MAUD Rietveld method [1]. To prepare TEM samples, particles were ultrasonically dispersed into 100% alcohol to form a suspension. Then a cement sample was obtained by dipping a carbon-coated copper grid support into the suspension for one second. TEM characterization was performed using Tecnai 20 (FEI) operating at both 200 kV and 120 kV with a LaB_6 filament and Titan 80-300 (FEI) at 300 kV with a Field Emission Gun (FEG).

3. Results and discussion

The typical morphology of the nanocement in Fig. 1a consists of lightly agglomerated nanoscale particles with an average size of 100 nm, in contrast with the typical particles of ordinary Portland cement (OPC) shown in Fig. 1b. The XRD pattern shown in Fig. 1c indicates that the dominant phases of the nanomaterial as C_2S and $CaCO_3$ (Fig. 1c) with the analysis shown in Table 1.

Characterization by TEM is performed with uniformly dispersed cement particles. Beam damage induced phase transformation of small particles (less than 100 nm) occurred essentially instantaneously on exposure to the beam, much too fast for the reaction path to be determined. Thus larger ones (no less than 100 nm) were chosen to study the chemistry before radiation since the damage to them occurred more slowly. Elements Ca, Si, O were observed from the EELS (Electron Energy Loss Spectroscopy) spectra (Figs. 2a–2c), which indicates the composition of the particle in Fig. 2b is C_2S rather than $CaCO_3$. After electron irradiation, the resulting microstructure of the particle is shown in Figs. 2d–2g. Fig. 2e is a high-resolution image taken from the region indicated by the arrow in Fig. 2d, demonstrating that the damaged particle consists of nano-sized subgrains with an average size of around 7 nm. Fig. 2f is a fast Fourier transformation (FFT) of the region in (b), which matches the selected-area diffraction pattern (SADP) in (g). The diffraction pattern can be indexed to the cubic CaO phase, indicating that a decomposition reaction transformed the C_2S to CaO and a siliceous product under electron beam irradiation.

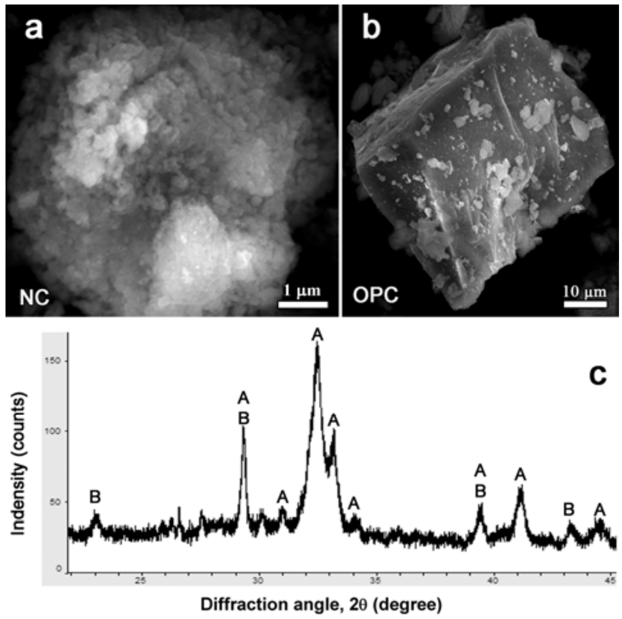

Fig. 1 SEM image of a typical nanocement (NC) aggregate (a) comparing with a particle of ordinary Portland cement (OPC) in (b). XRD pattern in (c) showing the principal phase of nanocement. A-C_2S; B-$CaCO_3$.

Table 1 Chemical analysis of nanocement by using Rietveld method.

Phases	Proportion in nanocement (Wt%)
C_2S	82.65
$CaCO_3$	13.79
Others	3.56

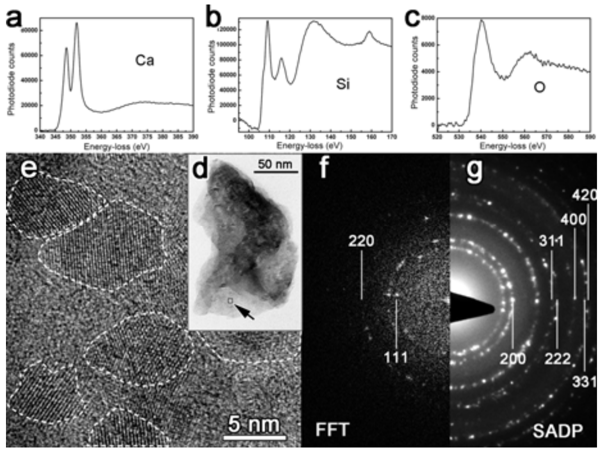

Fig. 2 EELS spectra of the cement particle in (d) before radiation damaged: (a) Ca, (b) Si, and (c) O. The existence of Si demonstrated the composition of the particle in is C_2S other than $CaCO_3$. (d) - (g) are the characterization of damaged products of the particle in (d). (e): high resolution image of the arrow indicated region in (d); (f): fast Fourier transformation (FFT) of image (e); (g): selected-area diffraction pattern. The index of rings in (f) and (g) indicates the existence of CaO after radiation.

In-situ observation of the phase transformation process of nano-C_2S was illustrated by a series of diffraction patterns in Figs. 3a–3f. Initially, a bright diffraction pattern near the $\bar{1}00$ zone axis were observed (Fig. 3a). The corresponding particle morphology is shown in Fig. 3g. With irradiation, the diffraction spots became weak due to the partial decomposition of C_2S [see spots in (b)], until most of the spots disappeared and an amorphous pattern was obtained after 29 min of irradiation (Fig. 3c). The particle corresponding to the pattern in Fig. 3c is shown in Fig. 3h. Amorphization is considered to be one of the signs of being radiation damaged. Similar phenomenon was observed in C-S-H phase in Ref. [6]. Volume shrinkage was also observed during the process [regions indicated by the black arrows in (g)]. After 36 min, new diffraction spots started to form (black arrows in Fig. 3d), suggesting the formation of new crystals. More spots appeared after 50 min of irradiation, indicating additional crystallization (Fig. 3e). Finally at 89 min, a well-shaped CaO polycrystalline ring pattern was obtained with the corresponding microstructure seen in Fig. 3i. The particle showed additional volume shrinkage, as shown in Fig. 3h (See regions marked with arrows in (h))

Fig. 4 shows the decrystallization process of C_2S in high-resolution mode using the Titan TEM. In order to have the time resolution to observe the reaction, a thicker region from a relatively large particle was chosen. At 0 min, a perfect crystal lattice was observed in the region circled by a dashed line (Fig. 4a). The lattice spacing is measured to be 0.261 nm, characteristic of C_2S, not $CaCO_3$. At 14 min of irradiation, partial amorphization has occurred (Fig. 4b) with close to complete amorphization after 16 min (Fig. 4c). During this process, CaO phase was not observed, most probably because the CaO nano-crystals formed in a different focal plane. The focal distance in high-resolution imaging is quite short (of order several nanometers), and thus it is not always possible to imagine multiple regions of a three-dimensional particle concomitantly with this approach.

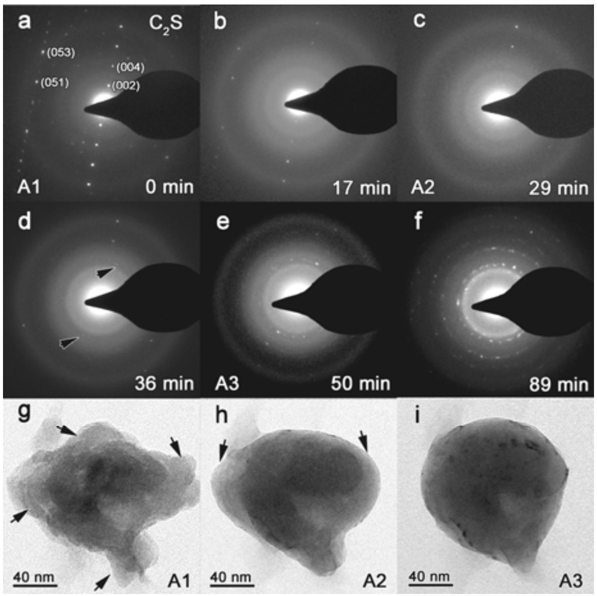

Fig. 3 Series of selected area diffraction patterns (taken by Technai 20) illustrating the radiation damage and recrystallizing process with time. [(a)-(f)]. The radiation time is marked at the right bottom of the diffraction. The corresponding relationship between special diffraction and particle morphology is marked by A1, A2, and A3 at the bottom of the image, which means (a), (c), (e) correspond to (g), (h), (i), respectively.

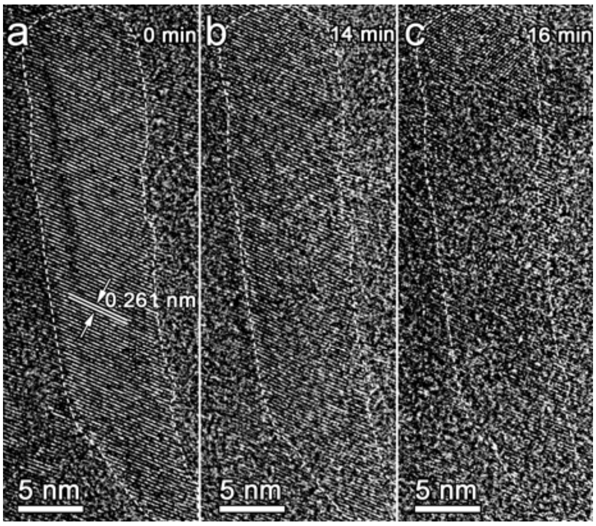

Fig. 4 Decrystallization process caused by radiation and observed in high resolution mode on Titan. The radiation time is marked at the right top of each image.

Decomposition of C_2S results in the formation of CaO in form of nanocrystals. Electron energy loss spectroscopy (EELS) was performed using the silicon L edges to investigate the form of the siliceous decomposition product. Each spectrum presented in

Fig. 5 was recorded for 10 s. Initially, distinct Si-$L_{1,2,3}$ edges were observed, which suggests the existence of Si^{4+}. The broad peak observed at about 131 eV was likely due to an inner-well resonance [11]. Five minutes later, the intensities of the Si-$L_{1,2,3}$ edges started to decrease, and continue to decrease with irradiation time. After 12 minutes of irradiation, an identifiable shoulder near 100 eV appeared, indicating the formation of Si^0 [3]. The shoulder became more distinct with time. After 66 min of irradiation, both Si^0 and Si^{4+} were observed although the Si-$L_{1,2,3}$ edges became more flat. Combining these results with the images of the microstructures in Figs. 2 and 3, we conclude that Si^0 and Si^{4+} are associated with the formation of amorphous Si and SiO_2 nanoscale phases, a result that is consistent with the observations of the development of diffuse scatter in the diffraction patterns.

We investigate the effect of electron voltage in order to further elucidate the mechanism of beam damage. Electron irradiation can lead to sample damage through several mechanisms, such as sample heading, knock-on (displacement) damage and radiolysis (bond breaking)

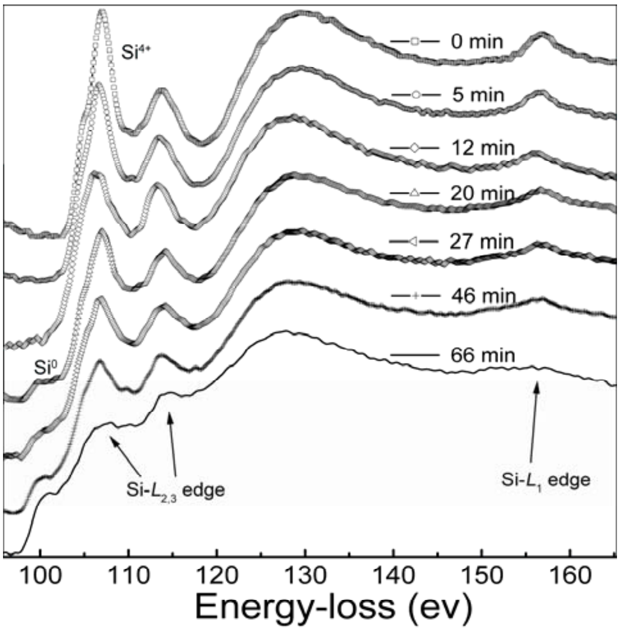

Fig. 5 Series of EELS spectra of Si edge, illustrating the effect of radiation with time. The Si-$L_{2,3}$ edge indicates the existing of Si^{4+}. The edge at about 100 eV indicates the formation of Si^0, which becomes more distinct with time.

[4, 5]. The gradual amorphization observed in Fig. 3 is consistent with a transformation from a crystalline lattice to an amorphous state, and suggests that electron-electron inelastic scattering is leading to radiolysis during irradiation of C_2S, while with further irradiation, the atoms reconfigure to form CaO. In general, radiolysis can be minimized by using the highest available accelerating voltage to reduce the inelastic scattering cross section [4, 5]. We found that the reaction rate was slower with a voltage increase from 120 kV to 200 kV using the Tecnai 20, a result consistent with radiolysis being the primary damage mechanism. Other ways to reduce the damage are using a smaller condenser aperture or taking pictures at lower magnification since both reduce the dose reaching the sample. Another form of damage to C_2S particle is through direct heating by the beam [5] since C_2S is a ceramic with low thermal conductivity. Beam heating may also lead to the observed volume shrinkage and the mass loss of C_2S particle shown in Fig. 3. To reduce beam heating-induced damage, carbon coating both sides of the TEM sample surface should help.

4. Conclusion

Beam damage to nano-C_2S particles during TEM observation was systematically investigated. C_2S particles are first amorphized, and then re-crystallized into CaO nano-crystals with average size of 7 nm surrounded by an amorphous matrix of Si and SiO_2. The reaction pathway suggested that the primary damage was radiolysis induced by electron-electron inelastic scattering. Beam-induced heating was determined to be a secondary cause of damage, leading to volume shrinkage and mass loss. According to the forms of radiation damage, methods have been proposed to reduce or even avoid the damage, such as using smaller condenser apertures, increasing accelerating voltage, and carbon coating the surface on both sides. This work will help understand the data collected from TEM observation of nanocement, and provide useful suggestions for performing future in-situ TEM studies of the hydration reaction of nanocement particles.

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Architecture, Faith and Culture Antagonism or Harmony?

Hassib Rehailia
Department of Architecture, Badji Mokhtar University, Annaba 23000, Algeria

Abstract: The relationship between architecture and faith has always been of great wealth. Faith as a way of life and social memory exercises a decisive influence on the shape of the construction environment. Yet this relationship is rarely analyzed. On a general level, one reason for this deficiency is probably due to the spread of the ideology of modernity. Given that modernity is implicitly secular, it does not prompt to understand faith in its relationship with other phenomena. It is the same for architecture. We believe on the contrary that the construction environment and the cultural aspect must interact and complement each other. When this is not true or only partially true, this results in user dissatisfaction, and refusal to engage and participate in the process of changing that environment. Many authors have tried to show explicitly the influence of Islamic thought on the social organization and the housing as well as the link between housing and identity, but its implications have not always been understood and transmitted concretely. One thing is certain: the ideological -symbolic-metaphoric sphere is the essence of architecture, as are the program requirements: functionality, distributivity, health of the environment and technology of construction. In this contribution we will address the thorny issue of cultural and religious influences on the choice of the morphology of the habitat and its components, and we will try to highlight the interaction between architecture, faith and culture through analysis of a Mediterranean type "House with Patio" as a particular architectural style, which has been enriched through the centuries by different cultures. Although the course of this typology in each of these cultures and at different times has not been the same, this has only strengthened the mission and spirit of the "Patio" until the appropriation of this model by the Arab-Muslim peoples who were able to incorporate the Islamic perception in this space.

Key words: Islamic Architecture, faith and culture, the traditional urbanism, Mediterranean cities.

1. Domestic Spaces

The Arab-Islamic culture has developed a representation of the very special place that has allowed its original identity. This spatial representation of the architectural framework is linked to living experience. It is all daily actions which constitute the appropriation of space by users. Thus, architectural or urban design would be pointless if we did not incorporate it in a study of living experiences, which give the space its temporal and spiritual evolution. The organization of the city in the Arab-Islamic world, is based on common concepts which are expressed differently depending on location, existing building materials, and economic and cultural development of each site. The traditional and popular aspect of these constructions manifests itself through the effect of natural or cultural environment, as well as all architectural features, structural and functional whose hidden meanings we will try to dissect and decipher.

The traditional house is "inhabited" by memory. The memory is built into the physical structures and imaginary space. Home memory does not only rely on images of specific acts, but also on pictures of places and names of the lineage as a guarantee of social excellence. The domestic memorial inscription is socialized and based on the use of the space as it evolves through the interactions between domestic players. Home memory takes shape through fitting into the domestic group structures and relationships that drive the social universe which occupies space and reinvents it each day [1].

Corresponding author: Hassib Rehailia, PhD, lecturer, research fields: architecture and applied arts, health, email:Hassib.Rehailia@gmail.com.

The "traditional" house was also, for travelers, writers or artists, a mysterious place, enigmatic and fascinating [2]. It has undergone multiple reflections, particularly as regards the relationship between physical structure and the religious and social organization of Islam and has also resulted in monographs of high quality [3]. There are many stereotypes, as outlined by A. Raymond, concerning the characteristics of the traditional house often described as belonging to a single model, invariable in space-time, isolated within the city, totally introverted, with a rigorous window on the outside and an exclusive opening on the inside with a patio. R. Ilbert [4] highlights the dangers using terms such as "Oriental", "Islamic" or "Arab" city (fig. 1), as well as ideologies that underpin it. Thus, whether the city or home, it is more prudent to get rid of misconceptions and uncontrolled designations in order to grasp the specificity of each space in its context.

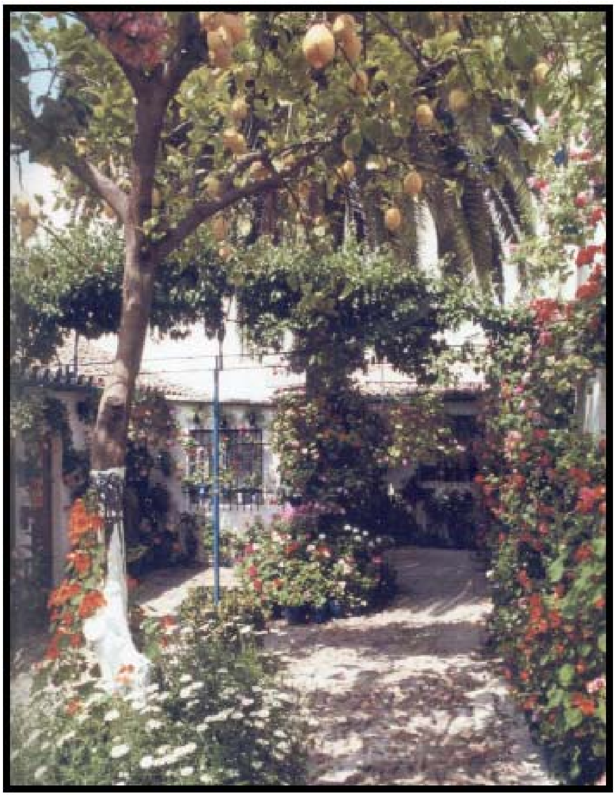

Fig. 1 A lemon tree in a Tunisian courtyard space provides shade in summer, while its size "high" passes the winter sun [5].

2. Cultural Influences and Theories about the Shape of the House

During the last decade, the relationship between domestic space and the society that uses it has been the subject of much discussion and research. Among these studies, the fundamental work of Pierre Bourdieu's on houses in Kabylia. In his research, he starts with a central reflection of placing the relationship between home and the ideological and symbolic parameters in correlations. For Bourdieu, the house is not only created by society, but should be considered as a framework in which children learn the rules that structure society, rules which themselves are created by society.

Bourdieu's study has caused other research dealing with villages in the Aures, the M'zab, and to a lesser degree the Atlas in southern Tunisia. This work has demonstrated explicitly the link between ideology, social organization and material homes. The attempt to define the organizational characteristics of the houses of the past and recent ethnography can help define boundaries in domestic spaces. This gives us different ways of looking at the effect of the cultural model on the shape of the house.

Suka Ozkan had the courage to devote an article to highlight the relationship between architecture, faith and culture. She insists that most cultural analysis have always sought to downplay the importance of religion, if they have not neglected it altogether, because of religion's political nature and standing in society: "The relationship between architecture or, more generally, between the building environment and faith has always been of great wealth. Faith as a way of life and social memory exercises a decisive influence on the shape of the building environment. Yet this relationship is rarely discussed. On a general level, one reason for this deficiency is probably due to the spread of the ideology of modernity. Given that modernity is implicitly secular, it does not prompt to understand the faith in its relationship with other phenomena. It is the same for architecture" [6]. It therefore seems important to explore the linkages between housing and social and cultural aspects of traditional societies. This does not mean that we neglect other influential factors on the choice of housing types and forms.

2.1 Vocabulary Space

The spatial vocabulary assigns names, in Arabic, to forms and spaces while emphasizing their content and their actions. This linguistic practice, both written and spoken, is strictly related to social and urban historical developments. The meanings of these names are often of great representative value of the image and the description we want to give space. The spatial and community vocabulary, linked to urban practices, allows us to better understand some socio-urban images and social behaviors.

We cite as an example in southern and eastern Mediterranean countries (predominantly Arab), the entire network from the alley until the dead-end represented by: darb (maze), the zoukak (narrow passage) The zankah (strangulation, alley which narrows along its path), the Khanka (suffocation, dead-end)...This illustration, which shows the correspondence between the perceptual image and its name, is a constant that we find both in urban and architectural domains. The many names designating the house and its components show the richness of this phenomenon. This variety of language adds to the space image as a temporal dimension that can not be perceived without prior training of the observer (Fig. 2).

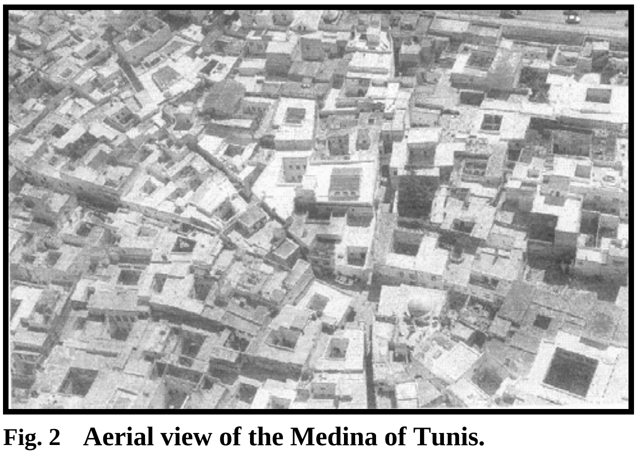

Fig. 2 Aerial view of the Medina of Tunis.

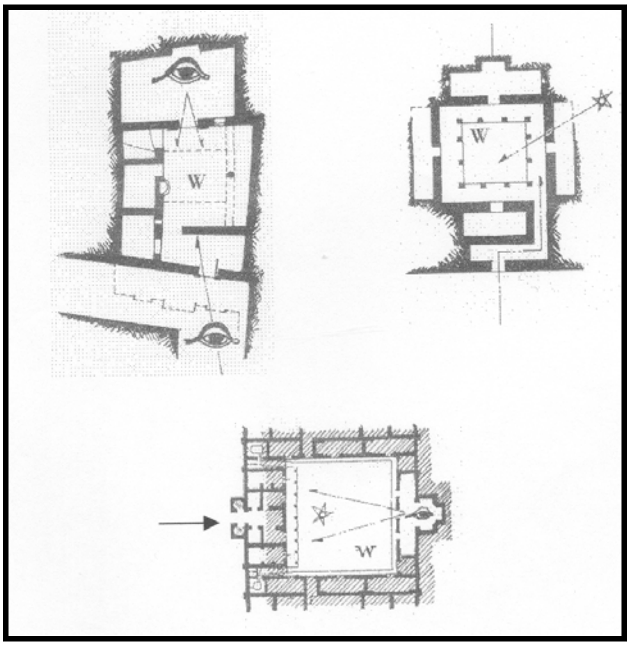

Fig. 3 Algiers: ground floor (staggered entry) [7].

The richness of the space-time vocabulary, combined with the architecture, provides a typology of spatial language that goes beyond the architectural formalism. It then creates new dimensions emphasizing understanding and images of space. This illustration which shows the correspondence between the perceptual image and its name is a constant that we find both in urban and architectural domains (Fig. 3).

2.2 The Domestic Threshold, Symbolic of A Border

The traditional planning is characterized by a long passage from private space to public space by introducing a “threshold” boundary that we try to describe t first, then the status of the “liminal space” [8] and some of its symbolic and practical purposes, then its interaction rituals that are, according to E. Goffman, the rules of politeness and civility, how to behave, the of protocol-oriented postures, and finally crossing between modes of public space and private space, emphasizing the basic texts and authors who have addressed these issues.

The threshold (Alley, corridor, entrance hall, vestibule), important structuring element, is primarily an imaginary line of separation, as an internalized gap between two entities constituting spaces, inside and out.

It is because there are fractures that these spaces take the quality of territories. The threshold is also a symbolic space in which to experience what binds the individual to the social body and in unties it. It marks the transition [9] between two completely different worlds. As an articulation point between home life and social life, in and out, the threshold is the symbolic "place" of the "in-between". As an articulation point, the threshold is also a "non-place" erected where the transition takes place, encounter and separation, thus a paradoxical element in that it allows and prohibits at the same time communication with others.

The social actor always generates the border and in return, the latter takes stage in the game of social reciprocity: Says Simmel about the symbolic role of the door: "Man ceases to be home when he walks past the door, and this means, of course, he breaks a part of eternity of the uninterrupted natural existence. But, if it is true that the shapeless limitation takes form, the boundaries he sets find their meaning and dignity only thanks to the symbol represented by the mobility of the door, with the ability to exchange at any moment this limitation in order to be free" [10].

It is A. Van Gennep who probably has best formalized the concept of "rites of passage". He showed that they all competed to mark a transition from one social state to another, a transition that introduces a time and a space to signal the difference between the prior and posterior state. Mr. Boughali defines rites of passage as both a manifestation of the end of a spiritual or social state and integration into another. These are "manifestations which are truly spatialized. It is in a space in its most material and terrestrial aspects that "the rites of passage" which rhythm existence integrate themselves" [9]. For P. Bourdieu, one must ask the theory of rite of passage questions about "the social function of the ritual and social significance of the line, the boundary, whose ritual makes lawful the passage, the transgression" [11]. Marking the passage with a line that establishes such a division of the social order, the ritual attracts the

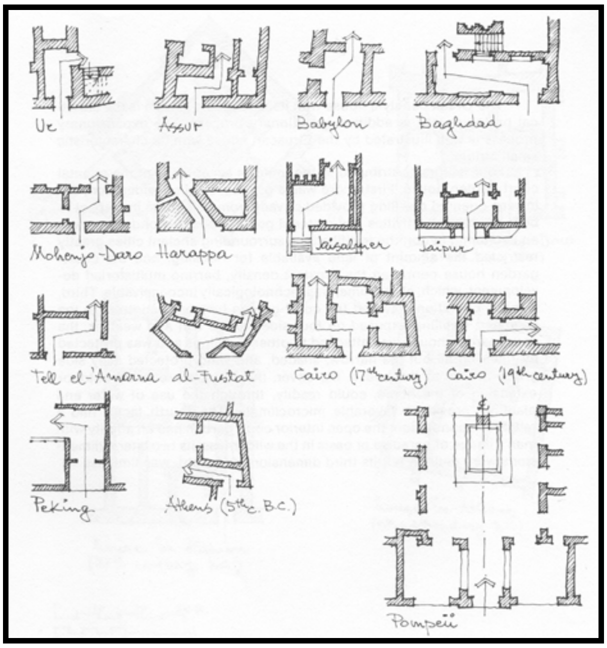

Fig. 4 Entries in different places and ages [12].

attention of the observer on the passage, while the more important, he says, is the dividing line that separates in a visible manner the before and the after.

In traditional homes, the entrance hall is usually set-up as a chicane and divided into two or three parts separated by a door (fig.4). Past the entrance, one finds himself in a stwan or sqifa, intermediate space where men wait for permission to cross the "border". A male visit results in the withdrawal of women from "visible" outer space. A space which generating first impressions and subjected to specific coding, it is also protected and part of a strategy of intimacy. The outer door remains open in general, a symbol of generosity and hospitality, referring to a social organization based on hospitality.

3. Conclusions

Despite their appearance as a basic courtyard house, in daily practice, the use of these forms gives Mediterranean houses a distinctly unique identity. Typographical analysis and spatial composition of homes have also shown that the design of the interior space of these homes is different. Indeed, the study of this model includes constant and variable features. We assert that these architectural and social practices are unchanging and reflect cultural and climatic influences of the region. They retain a considerable degree of adaptation in individual cases, because a theoretical model can not match the flexibility and spatial history of architectural practice, which is a major feature of Islamic tradition.

Muslim doctrine is at the origin of the design of these houses where the outside artifice is of little presence. This spirit is also reflected in the so-called Islamic architecture which gives an image of moderation, consistency and purity, with its maze of multiple spaces that allow both grouping and isolation, and finally with its judicious constructive systems and optimal use of materials.

Under the influence of Islamic thought, we notice that one of the characteristics of the urban Arab-Islamic morphology lies in the virtual absence of external marks of social distinction. This architecture features modesty and a moral ideal of equality, even if the interiors indicate clearly a search for distinction. This style is the result of mixing of three dominant factors: climate, religion and customs of its inhabitants, as well as building materials available locally.

The living space is a space “oriented towards ...” according to the reference culture. It is a constituent part of the cultural system. It gives codes of conduct and social representations. It is used to display what is prescribed and what is prohibited, especially around the categories of private and public. This opposition and its corollaries such as the oppositions inside/outside, familiar/foreign, near/far, male/female, could be considered as universal categories of human spirit that allow probing of the nature of the relationship that the resident establishes with his environment.

Arguably, the cultural unity of the Mediterranean cities was formed by the mixing of successive contributions influenced by social attitudes that prevailed in the area. The Arab-Islamic architecture is an architecture of forms, but it is not a formalist architecture. The comparison between Mediterranean cities reveals a number of basic elements common to all these architectures. These elements are also found in the Arab-Islamic architecture, such as the inlet chicane, the spatial articulations, the introverted court, zone separation, etc .... but each of these architectures has assimilated and interpreted these elements differently. A diversity of cultures is primarily determined in a global manner before being fragmented or amplified by the differentiated elements that have been joined together.

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