HANDS-ON-EXPERIENCE ON SEISMIC RETROFIT IN FOUR DIFFERENT COUNTRIES

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ABSTRACT

There are various different seismic vulnerability assessment procedures and seismic retrofit methods that have been applied to existing buildings in seismic regions. After the analytical assessment and design phase, it is of critical importance that the retrofit design is properly applied on-site. Conventional parties such as local authorities, construction culture, construction companies, quality of workmanship and availability of materials play a crucial role in the construction of seismic resistant buildings and in the selection of retrofit method and application. Furthermore there is a lack of experience on the performance of buildings subjected to earthquakes. Authors assessed and retrofitted eight reinforced concrete buildings and one masonry building from one to six stories in Nepal, Djibouti, Turkmenistan and Haïti, respectively, in 2011, 2013, 2015 and 2016. Retrofitted buildings in Nepal were subjected to 7.8 magnitude earthquake in April 2015, which gave authors the opportunity to document the seismic performance. This paper summarizes the hands-on-experience gained from four different seismic assessment and retrofitted projects conducted in four different countries. Performance of the retrofitted buildings subjected to a 7.8 magnitude earthquake and difficulties in the application of retrofit are present.

Keywords: implementation of retrofit, retrofit design, Seismic assessment, seismic retrofit, site survey

1 INTRODUCTION

Structural engineering has learned a lot from previous earthquake hazards. Seismic codes have been improved and reviewed after each earthquake event, which leads to investigation of earthquake safety of existing buildings. This need is more pronounced in seismic active regions. Obermeyer was commissioned to carry out the seismic assessment of nine buildings worldwide. This paper presents the practical experience gained in four different countries and the related findings. The project locations can be seen in Fig. 1.

Effect of various aspects like characterization of seismic hazards, performance of non-structural systems, costs of retrofit and public policy is thoroughly discussed and summarized in Holmes [1]. Owner's investment strategies, construction cost, disruption to the building users, aesthetics are the important parameters need to be considered during the whole evaluation process [1]. Review of various building codes, different structural materials, building techniques and seismic retrofit methods in three different countries such as USA, Italy and New Zealand are reported in Ref. [2].

2 ASSESSED BUILDINGS

2.1 Available documentation

The degree of information level about the geometry, details and material properties is very important for the seismic assessment and strongly dependant on the construction year. Detailed drawings and calculations are available for recently built structures, but there is often a lack of information for older buildings. Nonetheless, drawings and calculations are only unconfirmed information and need to be checked on site. Especially as-built drawings were, according to experience, often inaccurate, incomplete, and only helpful in preparation

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Figure 1: Project locations.

of the site survey. Digital copies of drawings in, for example, dwg-Format, are the exception. Standard are hardcopies of existing plans, which are often hard to read because of their inadequate quality.

Availability of floor plans, reinforcement plans, structural calculations are one of the most important information sources. Table 1 gives an overview of the available information for the assessed buildings.

Table 1: Available documentation.

Location	Available documentation	Comments
Nepal – Kathmandu (5 buildings built between 1979–2002)	• Former seismic assessment report • Geotechnical report for foundation design • As-built drawings • Architectural drawings • Structural drawings and details partly available	In general an adequate number and quality of documentation is available. Information has to be verified during the site survey.
Djibouti – Djibouti (built in 2008)	• Architectural drawings • Structural drawings • Description of construction type	Reinforcement information available but only in principle.
Turkmenistan – Aşgabat (built in 1993)	• Architectural drawings	Architectural drawings in deficient quality. Major differences between architectural drawings and as-built situation.
Haïti – Port-au-Prince (2 buildings built in between 1985 and 2013)	• Architectural drawings • Structural drawings partly available • Soil report partly available • Photo documentation of construction period	Architectural drawings in partly deficient quality.

Table 2: Structural type.

		Existing Buildings			
		Construction Type	Construction Year	No. of Stories	Design Code
Nepal	Building 1	RC Frame	1979	3	Nepalese Building Code NBC (based on Indian Building Code) [3]
	Building 2	RC Frame	1979	2	
	Building 3	RC Frame	2002	3	
	Building 4	RC Frame	2001	1	
	Building 5	RC Frame	1996	6	
Djibouti [4]	Building 6	RC Frame	2008	3	Code parasismique 69, PS69 (French building code 1969) [5]
Turkmenistan	Building 7	RC Frame	1993	5	SNIP [6]
Haïti	Building 8	RC Frame	2013	5	ASCE [7]
	Building 9	URM	1985	2	N.A.

2.2 Buildings structural system

Except of one unreinforced masonry building in Haïti, all buildings were reinforced concrete structures where the seismic loads are resisted by frames. More detailed information about 9 buildings can be seen in Table 2. Assessed buildings have a storey range of one to six. Year of construction varies between 1979 and 2013.

3 ASSESSMENT PROCEDURE (GENERAL)

3.1 Site survey

On the basis of the available information the assessment starts with a site survey. The survey program for a building is developed after the detailed review of all documents.
The objective of the survey efforts is to be able to set-up a most realistic simulation model of the buildings in order to rate their behaviour under earthquake loads and to determine necessary strengthening measures.
The major constraint is often that no information of the structural system is available. The investigation program in general is:

1. Assess the building's geometry, using digital measuring equipment and cross check the provided plans to identify the level of accurateness and reliability.
2. Identify the building's structural elements like concrete columns and beams using visual inspection, thermal imaging and magnetic field scanning to understand the overall load bearing system and the connection points.
3. Identify and rate possible shear walls, using visual inspection, thermal imaging and magnetic field scanning, to identify the three-dimensional bracing of the construction.
4. Non-destructive testing by means of reinforcement scanners at representative structural parts of the building to identify and to quantify the reinforcement inside the structural elements.

5. Destructive testing by means of opening representative structural parts to verify the reinforcement scan results.
6. Schmidt hammer concrete tests to verify the provided data of the former assessment reports.

A reinforcement scanner is a very efficient tool in order to get information about the diameter, spacing, and concrete cover of the in-built reinforcement. Different scan types can be used to verify existing reinforcement. Application examples can be seen in Fig. 2. The left picture shows a 'Quick scan', which IS used to determine the existence, distance, and concrete cover of reinforcement bars. The right picture shows an 'Image scan'. An 'Image scan' shows the distribution of rebars in a section and gives additional information on rebar diameter. If necessary and allowed by the customer, destructive tests on few selective locations are a suitable for validation.

An additional tool for non-destructive testing is a thermal image camera. Thermal imaging is used in areas where it is not possible to apply (non-)destructive testing or where the structure part is not easily reachable. Different heat absorption and emission of used materials show a clear separation of e.g. structural and non-structural parts.

It is a very helpful tool in order to give the structural engineer an insight about the structure. Application examples can be seen in Fig. 3. The two left pictures show the existence of a joint between two building parts in the thermal image and afterwards verified by a destructive test. The destructive was done to determine the used material for the joint.

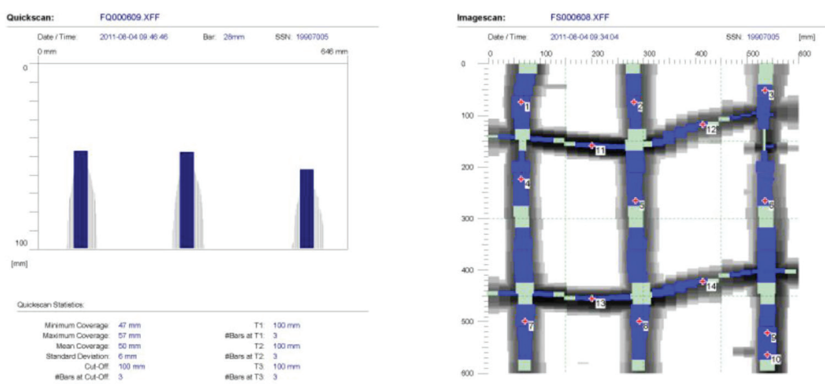

Figure 2: Use of ferroscans.

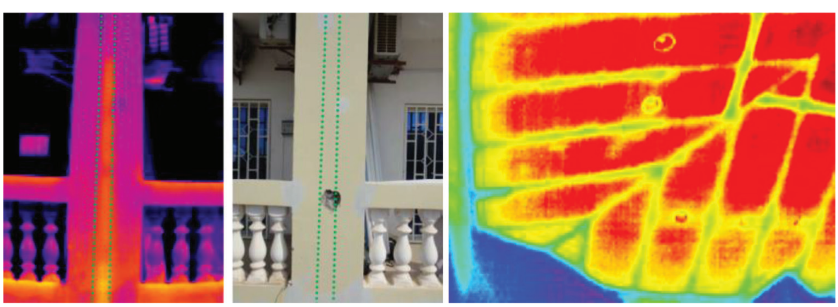

Figure 3: Use of thermal camera.

The right picture shows a load-bearing roof structure. The roof structure was covered by wooden panels from the inside but it was able to determine the metal construction by the use of thermal imaging.

3.2 Assessment

Most common methods to assess existing buildings on the base of linear and nonlinear methods are elastic linear static (lateral force) analysis, elastic linear dynamic (multi-modal response spectrum) analysis, nonlinear static (pushover) analysis and nonlinear dynamic (time history) analysis.

Selection of the method is the common decision of the structural engineer and the client. Desired level of safety, seismicity of the region, importance of the building, duration, and costs of the assessment method are the major factors effecting the selection. The client should be informed by the structural engineer about the pros and cons of each method and about the consequences. Based on the site-survey results, it could also be concluded that the building does not meet the safety requirements and no further assessment is necessary for the building.

Elastic linear dynamic analysis is conducted for building one to eight. Seismic demands were compared with the capacity of the members. Based on the results and distribution of the DCR (demand capacity ratio), the final decision of the necessity of the retrofit was made. Table 3 shows the PGA (peak ground acceleration) values used in the analysis and the type of assessment method.

For the Unreinforced Masonry Building (Building 9) linear static analyses was conducted. Building 9 has experienced 2010 Haïti earthquake and masonry walls had cracks, which reduces the strength of the walls considerably. Based on the results it was concluded that further investigation is not necessary and that the building does not meet the seismic safety criteria. A retrofit of this building is economically unfavourable.

There was no code for the seismic assessment of the existing buildings in all four countries. In agreement with the client, Obermeyer used Eurocode 8 [8], Uniform Building Code [9] and Turkish Earthquake Code [10] in order to be able to reflect the material and workmanship quality, dominant construction types, and local seismicity. Turkish Earthquake Code [10] was selected considering the construction practice and quality of the four countries. An example

Table 3: Buildings assessment overview.

			PGA(g)	Method	Retrofit
Nepal	Building	1	0,4	Linear Dynamic (DCR)	Yes
	Building	2	0,4	Linear Dynamic (DCR)	No
	Building	3	0,4	Linear Dynamic (DCR)	Yes
	Building	4	0,4	Linear Dynamic (DCR)	Yes
	Building	5	0,4	Linear Dynamic (DCR)	Yes
Djibouti	Building	6	0,1	Linear Dynamic (DCR)	No
Turkmenistan	Building	7	0,4	Linear Dynamic (DCR)	Yes
Haïti	Building	8	0,3	Linear Dynamic (DCR)	No
	Building	9	0,3	Linear Static (DCR)	Yes

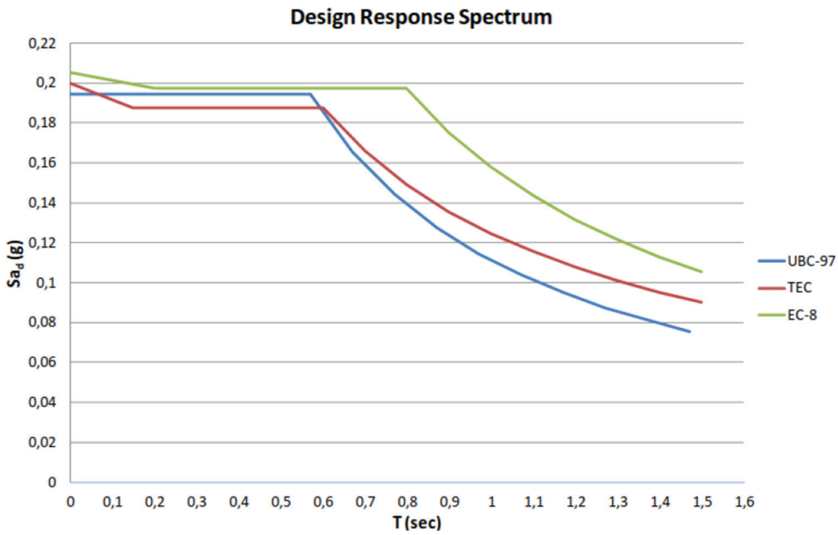

Figure 4: Design response spectrum.

response spectrum obtained from three different codes can be seen in Fig. 4. As it can be seen, constant acceleration plateau of the three different code spectra are in agreement.

4 APPLICATION EXAMPLES

4.1 Kathmandu, Nepal

Nepal with the Kathmandu valley is situated in an active seismic zone. Pandeya *et al*. [11] investigated in the recent past the microseismic activity between 1994 and 1999. Concluding, for earthquakes with magnitudes >8 the following statement will be cited here: 'We infer four 250–400 km long segments that could produce earthquakes comparable to the M = 8.4 Bihar–Nepal earthquake that struck eastern Nepal in 1934. Assuming the model of the characteristic earthquake, the recurrence interval between two such earthquakes on a given segment is between 130 and 260 years.' This is probably based on conservative model assumptions neglecting minor seismic stress releases but gives a comparable value for the hazard evaluation.

As requested by the client the Nepalese standard NBC 105:1994 is the basis for the seismic assessment. For the design of buildings the seismic level in NBC 105 is based on a return period of 50 years. Further, with the assumed lifetime of a building in Nepal therein of 30 years this corresponds to a 45 % chance of exceedance in 30 years. Compared with most international regulations for earthquake safety and design these values seem to be very unconservative.

From an engineering perspective it can not only be the aim to fulfil certain code regulations without considering background information or state of the art research and engineering knowledge. Therefore we suggested using design earthquake loads that correspond to international standards without neglecting the national specifications following from the Nepalese codes.

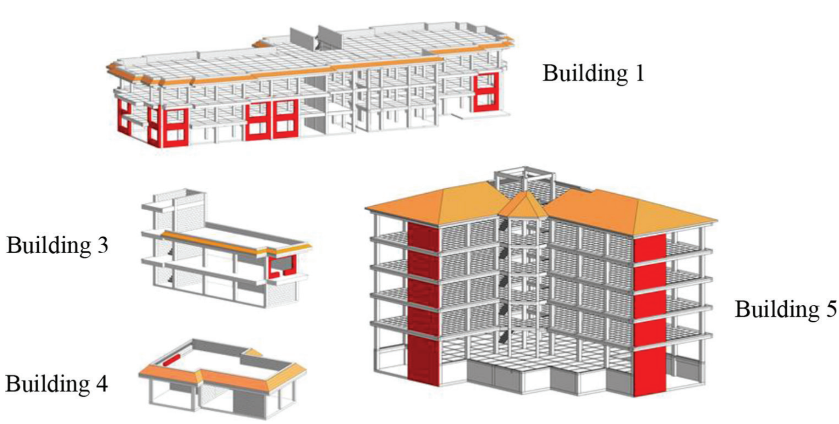

Figure 5: Retrofit design.

Parts of the structures of the buildings, which are under consideration here, already exceed the estimated lifetime of 30 years. Taking into account that the 1934 Bihar–Nepal earthquake is expected to have a return period of 130–260 years it seems reasonable to consider the 475 years return period earthquake, which refers to a 50 years building life, for structural safety calculations.

Based on the result of the seismic assessment procedure, Obermeyer planned seismic strengthening adding reinforced concrete shear walls. The proposed locations of shear walls can be seen in Fig. 5.

4.2 Aşgabat, Turkmenistan

Aşgabat is located in an active earthquake zone. In 1948 an earthquake with magnitude 7.3 has occurred near Ashgabat and destroyed nearly the whole infrastructure. The epicentre of the earthquake was located 25 kilometres southwest of Aşgabat. Peak ground acceleration could be determined as 3.8 m/s^2 for a seismic event of 10% exceedance in 50 years.

The building under consideration was built in 1993 as a hotel building. The customer will use the building as an office building. The whole reinforced concrete construction was separated into five parts using construction joints as a requirement of seismic safety. An inclined and a plane steel roof composed of steel truss members are the two parts of the steel construction.

As previously discussed, conventional parties such as local authorities, construction culture, and construction companies are important in the application of retrofitting together with quality of workmanship and availability of material.

Based on the result of the seismic assessment procedure, Obermeyer planned seismic strengthening adding reinforced concrete shear walls. The proposed locations of shear walls can be seen in Fig. 6.

However, the construction company started to use steel bracings without the agreement of Obermeyer, which would definitely not substitute RC shear walls in terms of stiffness and strength properties. Additionally, the use of steel bracings needs a proper workmanship that was not available on site. Quality of welding seams was inappropriate as well as connection to reinforced concrete parts. The only way to react to these circumstances was the addition of supplementary steel bracings.

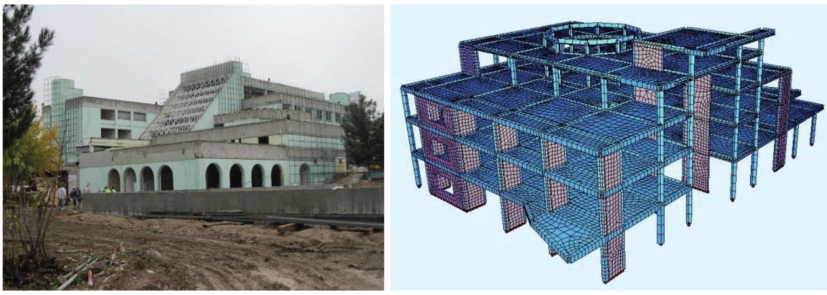

Figure 6: Retrofit design.

Obermeyer could fortunately avoid the replacement of reinforced concrete shear walls by steel bracings in the most affected areas in the lower floors.

Figures 7 and 8 show the improper application of welding beams and bolted connections. Additionally, Fig. 8 shows the inadequate connection to existing reinforced concrete load-bearing parts.

Figure 7: Unplanned use of steel bracings.

Figure 8: Inadequate workmanship.

Figure 9: Shear walls made of reinforced concrete.

Figure 9 shows the non-consideration of the retrofit design by local HVAC and electrical installation.

5 OBSERVATIONS NEPAL 2015

Obermeyer carried out a seismic assessment of five building in Kathmandu, Nepal in 2011. Four of the assessed buildings On 25 April 2015, an earthquake occurred with a magnitude of 7.8 M having the epicentre in the Gorkha district followed by multiple aftershocks. In Kathmandu, recorded peak ground acceleration was approximately 0.10–0.15 g. Large spectral accelerations are observed due to the site amplification at the periods of 2–4 seconds [12].

Rapid damage assessments have been conducted in April and May 2015 by local contractors after the earthquake to all previously assessed and retrofitted buildings to assess the safety. Additionally, Obermeyer went to Kathmandu to observe buildings and damages related to the earthquake.

5.1.1 Building 1

Building 1 experienced only slight damage. Mostly fine hair cracks were observed in column to beam connections.

Fine cracks were observed in beam joints, joints of beam and wall, and joins of shear wall and brick masonry wall in all storeys. In first floor slab experienced hair cracks (Fig. 10).

Figure 10: Results of damage assessment – building 1.

As a result of post-earthquake site survey building can be used for office occupancy. Retrofit of cracks is necessary.

5.1.2 Building 2

A retrofit of Building 2 was done prior to the assessment of Obermeyer in 2004/2005. Building 2 experienced damages but life safety criteria were still achieved.

Minor cracks on top of beam level and non-structural cracks were observed. Pounding happened between northwest staircase block and office building (Fig. 11).

Building can be used for office occupancy. Retrofit of cracks and staircase is necessary.

5.1.3 Building 3

Building 3 experienced only slight damage in form of non-structural cracks.

In joint of wall and column in ground floor separation cracks were observed together cracks in first floor walls.

Cracks are non-structural cracks. Building can be used for office occupancy. Retrofit of cracks is necessary.

5.1.4 Building 4

One storey building 4 experienced minor damage in form of cracks in non-structural walls.

Building can be used for office occupancy. Retrofit of cracks necessary by means of strengthening with injecting epoxy or grouting is necessary (Fig. 12).

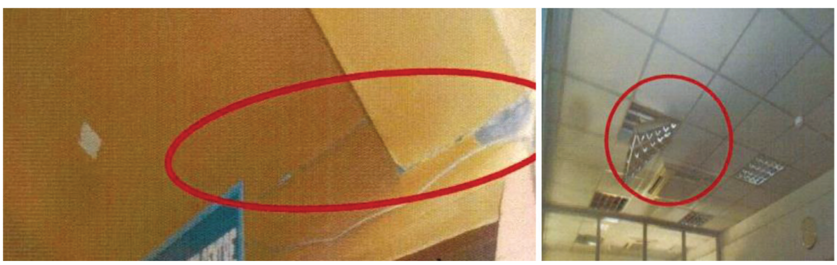

Figure 11: Results of damage assessment – building 2.

Figure 12: Results of damage assessment – building 4.

6 CONCLUSION

Seismic assessment of the existing buildings is a challenging task. Every earthquake event enhanced the knowledge of practicing engineers. Performance of buildings after a seismic event gave the engineer the opportunity to validate his design and quality of the application. Observation of damages after 2015 Nepal earthquake of five buildings previous assessed and partly retrofitted by Obermeyer is shown in this paper. Experienced slight damage by all buildings agreed to Life Safety Performance Level targeted during retrofit design.

Moreover, difficulties by the implementation of a proper retrofit design through local parties are observed in some of above mentioned countries.

As it could be concluded from this paper many factors play an important role through the whole process. Not only the type of numerical analysis and complicity of them but also the local practice and parties are very important to reach an optimum seismic assessment.

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