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Appropriate Structural System Selection for Mid-Rise Buildings in Afghanistan

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Abstract: ***There are various systems in building envelope, among all of them structural systems governs the overall characteristics of the building, it includes lateral load and gravity load resisting systems. This study conducted to select and propose appropriate structural system for mid-rise building, the selection analysis process were done in three stages. Stage one is based on the limitation and constraints in the use of various structural system in Afghanistan, questionnaire surveys were conducted to find-out the limitation and constraints to different criteria of the structural system in Afghanistan. Stage two evaluate the limitation and constraints to selected appropriate structural system. Several requirements, criteria and sub criteria of structural system were identified. For clear concept and verifying proposed model case studies conducted in six zones of Afghanistan. Stage three is the review of the current status of various structural systems for building, fourteen interviews were conducted.***

Keywords: Structural System, Limitation and Constraints, Structural System Selection, Analytical Hierarchy Process, Current Status of Various structural systems in Afghanistan

1. Introduction

Building is basically an envelope which surrounds and subdivides space in order to create a protected and safe environment for live beings (Angus J. Macdonald, 2001). [1] Generally building are classified by various types of systems, e.g. architectural, structural, mechanical, plumbing, security and other systems, which are rationally and logically combined and integrated with building service functions (Heiselberg, 2009) [2]. All excitation and loads tends to distort the building, therefore, the building envelope need and demands a system to keep the building safe and stand, this system is called structural system fig(1).

This study conducted in Afghanistan, which has experienced three decades civil war and conflict, in recent many infrastructure projects are undergoing. According to the American Special Inspector General for Afghanistan Reconstruction (SIGAR, 2012 & SIGAR, 2013) report, most of the completed and undergoing projects were not designed according to the Afghan Buildings Codes (ABC), national regulation and requirements, even though the cost of the most implemented building projects are high, but the projects quality is shown as low or can‘t meet the requirement of usage. Although Afghanistan has had Afghan National Building codes (ABC), but Hall (2013) survey shown that less than 42 percent design professionals in Afghanistan have awareness about ABC codes existence. [3] [4]

Most of the design professionals in Afghanistan are using international or different foreign building design codes. They reasoning that Afghan Building Codes are not well updated and are not efficiently usable. According to Anwar (2012) the design process are classified by three main phases, Conceptual Design, Modeling Analysis and Detail Design, selection of structural system is a conceptual design, which is vital important, and has efficiently effects on the overall performance and the cost of the building.[5] Selection of structural system for building is a complex, multidisciplinary procedure. No building design project is alike, in case basic knowledge about structural system and its criteria alone with intuitive power is needed to elect appropriate structural system for building. There are certain criteria that are commonly true in the primary phase of evaluating different structural systems. These criteria include all aspects of a full, functioning building and forcing the design team to be creative in their approach of satisfying all aspects.

Figure 1: Structural system

Hence, lack of relevant building code, formed structural selection ideas creates serious problems, and does not yield suitable output of structural system and building design. Therefore, it is needed to find out all the limitation and constraints which have effects in the building structural design, and propose an appropriate structural system in the view of the limitation and constraints for buildings in Afghanistan.

2. Objective

This study is conducted to find out all the structural design limitations and constraint, then select and propose appropriate structural system for mid-rise building in Afghanistan.

3. Methodology

With consideration of limitation and constraints, there are

lack of rigorous and systematic methods in existence for selection of new appropriate structural system. Most of the current structural system selection approaches were criticized for overemphasizing the financial and quantitative characteristics, which was easy assessable, but overlooked other benefits such as improved social acceptable, human comfort, environmental sustainability, site applicable and building flexibility. (Wong et al., 2008)[6]. Based on existence of qualitative and quantitative data Modified Analytical Hierarchy Process (MAHP) approach is proposed to evaluate and select appropriate structural system, and examine by Scenario analysis.

Thomas L.Saaty developed Analytical Hierarchy Process in 1980. It is a mathematical decision-making process which helps to elicit preference judgment from decision maker and researchers. As stated Schmoldt (2001) AHP for more than 7 criteria can be analysis by multi criteria direct rating process, it is called Modified Analytical Hierarchy Process M-AHP where by direct rating method we can compared the criteria. MAHP adopts both quantitative and qualitative approaches to deal with complex decision problems. In this research study building structural system is divided into three hierarchical levels of criteria according to (Bennetts et al., 1995; Golabchi, 2008; Wong et al., 2008). [6]- [10]

First level of hierarchy consists five different requirements which is further divided into 31 criteria, and again there criteria is further divided by 110 alternative sub-criteria. All there requirement, Criteria and sub-criteria will used to determine different structural systems (Lateral load resisting system, Floor System, and Foundation) see fig (2). All these criteria govern the final results of structural system of all types of building, basic, structural, planning, construction, design and ownership requirements, use equation-1.

1) Make Hierarchy system of different criteria, sub-criteria and alternatives of the complex problem is developed after identification of relevant attributes.
2) By assigning numerical value the attributes is compared and decision is done. The decision should not be subjective but should assign as an expert insight.
3) Weight and score to attributes are given relative to each criterion.
4) Weight and score are calculated using below formula (Anwar, 2003).[11]

$$V_1 = \sum_{i=1}^{m} A_i S_i \left(\sum_{j=1}^{n} B_{ij} S_{ij} \left(\sum_{k=1}^{p} C_{ijkl} S_{ijk} \right) \right) \quad \ldots\ldots 1$$

Materials

Purposive sampling method was done in this study. According to Marshall (1996) the purposive method is known as judgmental sampling method and convenience method, in which researcher selects samples according the objectives. For example, specific population who has specific knowledge and experience building design in Afghanistan. For qualitative data collection we conducted interview with design experts. The sample size judgmentally selected (42) designer and (14) experts. [12]

Data Analysis

Both qualitative and quantitative data analyses were done with the help of primary and secondary data. In this study. Qualitative analysis is used to show the current status of various structural building, and qualitative analysis used to select appropriate structural system for mid-rise building, by help of secondary data, intuitive power of design and selection of structural building.

Qualitative data analysis simply done by labeling and coding the important words related it helped to understood the current states of various kinds building in Afghanistan. Quantitative analysis evaluated the limitation and constraints in the use of various structural system of building. MAHP is use to evaluate and select appropriate steel structural system by using primary data and secondary data. MAHP used primary data to give weight to each criterion i.e. input and primary and secondary data will both used in giving score to structural system. Sensitivity and Scenario analysis is done to see the impact of each criterion or sub criteria in output result. These data were collected, computed and processed by using Microsoft Excel computer program see table (1).

In this study two level main criteria and sub-criteria of hierarchy which are given weights will consider, so the formula becomes eq#2:

$$V_1 = \sum_{i=1}^{m} A_i S_i \left(\sum_{j=1}^{n} B_{ij} S_{ij} \right) \quad \ldots\ldots 2$$

Where:

V_1 The total Value of system '1', indicating its limitation
A_i Normalized weight of the first level criteria *i* of m criterion
Bij Normalized weight of the *j* sub criteria in *i* main criteria
Si Required or preference score given to the main criteria *i*
Sij Requirement of preference score given to the j sub-criteria in *i* main criteria

For unambiguous results the Likert five-point scale was selected which is easy to interpret. Date entry table shown in Table1.

Table 1: Criteria Weight and Score Table

No	Requirement	Criteria	Sub-Criteria	Average Normalized Weight (for each criteria sum should be 100 or 1)		Criteria Weights and Scores					
						System-1			System-2		
				Weight A_i	Weight B_{ii}	S_{ii}	S_i (B_{ii}xS_{ii})	V_1 (A_ixS_i)	S_{ii}	S_i (B_{ii}xS_{ii})	V_2 (A_ixS_i)
1	A			A_1							
2		A_1			B_{11}						
3			$A_{1.1}$			S_{11}	B_{11}xS_{11}	A_1xS_1	S_{12}	B_{11}xS_{12}	A_1xS_2
4											
5											
6											
7											
8											
9	Z			Am							
10		Z_m			B_{mn}						
11			$Z_{m.n}$			S_{iim}	B_{mm}xS_{iim}	A_mxS_{im}	S_{iim}	B_{mm}xS_{im}	A_mxS_{im}
Total Sum of weight and Score of sub-criteria							$\sum_{-1} S_i$			$\sum_{-2} S_i$	
Total Sum of weight and Criteria Score								$\sum V_i$			$\sum V_i$

The verification of this study was performed with the help of case studies of ten stories Residential building in six main zones (Khost, Kabul, Kandahar, Nangrahar, Herat and Balkh) Afghanistan. During case study, all the features of building were used for structural design and also several limitation and constraints. This research deals with both Lateral Load Resisting and Gravity Load Resisting systems. Steel, Precast and Cast-in-Place concrete and all types of the structural systems which are classified from various sources

standards books (IBC 2013, Afghan Building Codes (ABC), ASCE 2006, ANSI/AISC 360-10), (Bungale S Taranath, 2010), (Bungale S Taranath, 2011) research papers, articles, and etc.[11]

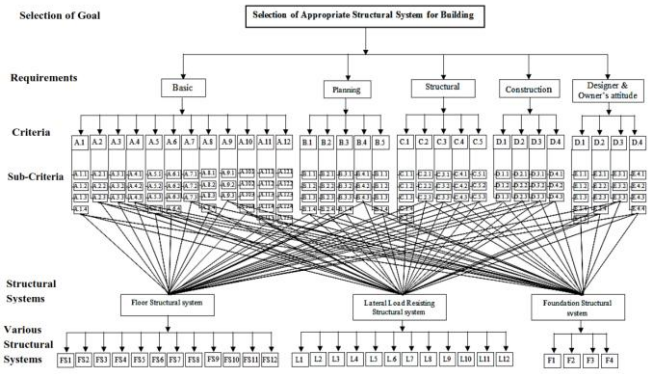

Figure 2: Limitation vs. Steel

All criteria weights first calculated and ranked according to their mean weight ratings. The mean weights rating were calculated using the following formula:

$$Average\ Weights = \frac{\sum Weights\ of\ each\ criteria}{\sum Number\ of\ the\ participants} \quad \ldots\ldots 3$$

The result clearly shows degree of limitation, the higher the weight value the most limited the structural system. For clearly and easy realize weights of each criteria shown in bar-chart for each zone separately, those criteria which have weights rate is less than 3 are hidden see fig bellow.

Khost Zone:

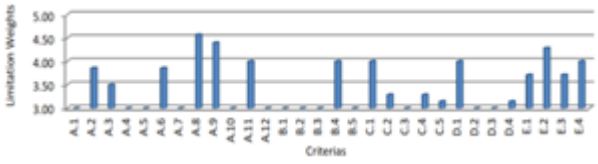

Figure 3: Limitation vs. Steel

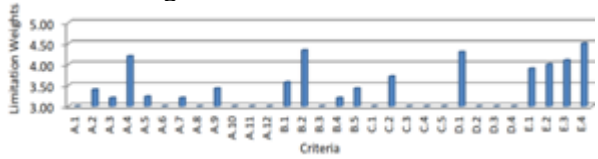

Figure 4: Limitation vs. Pre-cast Concrete

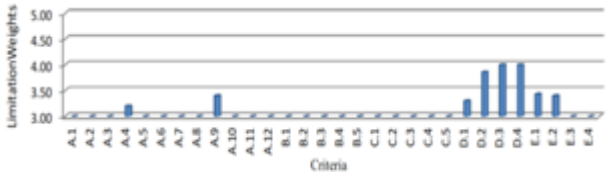

Figure 5: Limitation vs. Cast-in-Place Concrete

The above diagrams show that limitation and constraints verse steel and precast is high but cast-in place is shows few, same for other zones also. Structural system selection were performed with the help of limitation and constraints, site inspection, design expert scoring.

4. Result and discussion

This Study found that most common limitation in the use of various structural systems for building in Afghanistan are:

Steel structural system: None availability of steel structural materials, High cost, Fire Safety, Construction technology, Designer and owner‘s attitude, Roof layout and column layout geometry

Verses Precast Concrete Structural System:
Seismic Load Excitation (Afghanistan is in high seismic risk zone. East, central and south-east parts are in high seismic risk, which prevent the use of precast concrete structural building), number of stories, old construction technology, designer and owner‘s capacity and attitude

Cast-in-Place Concrete Structural system:
Seismic Excitation, construction Time, and complex construction Process. Score assigned for each sub-criteria, mean and normalized weights to the structural system were entered to the Microsoft Excel spreadsheet for each zone separately. The formula was calculated by the selecting one sub criteria from each alternative, sub-criteria and weights were input to all the requirements and criteria. The calculation gives different suitability values for each individual system, the higher the output value by model the most appropriate the structural system, this study verified by cause study of six story building for each zone.

Structural Systems:
Suitability for respect structural systems shows by percentage in bar-chart in figures below for each zone separately.

Set your page as A4, width 210, height 297 and margins as follows [3]:

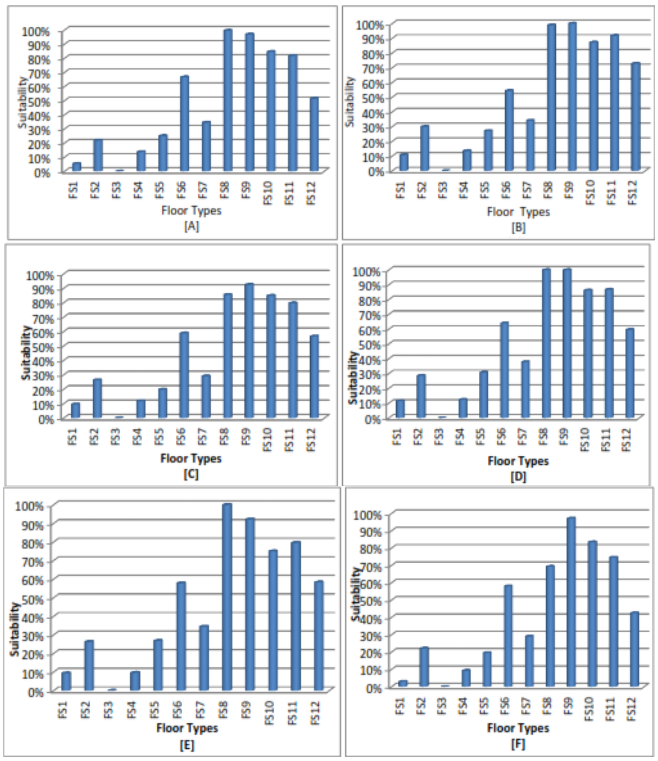

Figure 6: Floor Structural System M-AHP Selection

Foundation Structural System

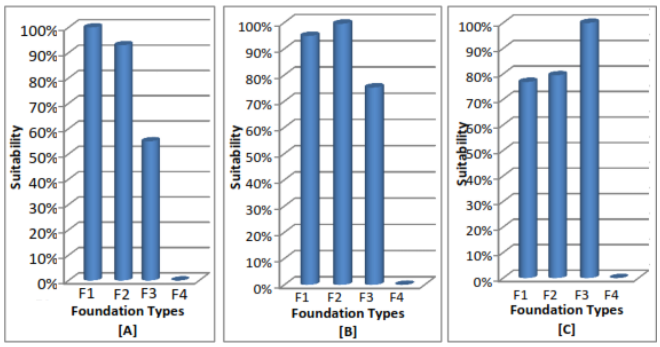

Figure 7: Floor Structural System M-AHP Selection

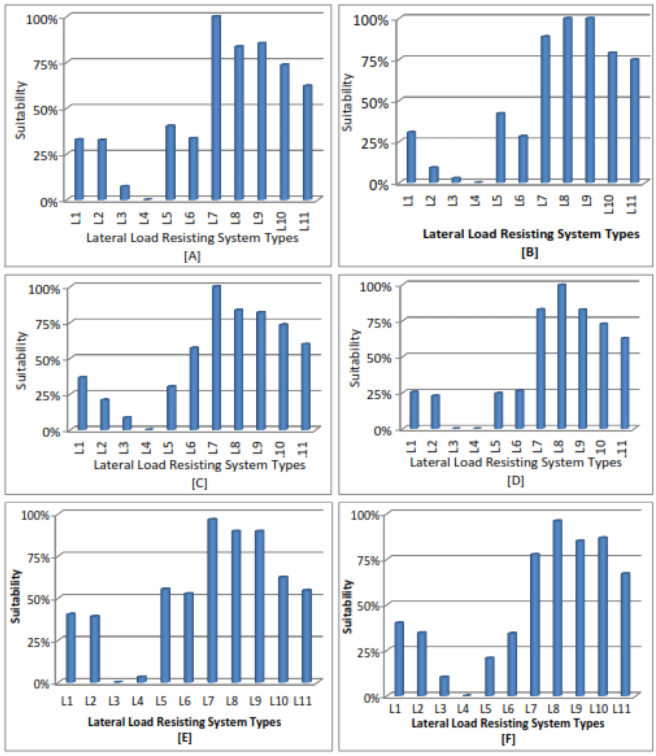

Figure 8: Floor Structural System M-AHP Selection

The floor structural system features were input in the model after that, the suitability value were calculated by modify analytical hierarchy process with multi criteria formula. The higher the value of percentage the most appropriate the structural system, bar-chart shown the result in Figure (6, 7 & 8). The A, B, C, D, E, and F alphabet latter represent Khost, Kabul, Kandahar, Nangrahar, Herat and Balkh Zones respectively.

Current statues study shows that beam-slab, beam-column and mat foundation are common practice for midrise building in Afghanistan, but with consideration of all constraints and limitation MAHP analysis result bar-chart in Figure -6 shows that low seismic zones Cast-in-Place Concrete Two-way Flat Plat (FS9) floor system is highly appropriate and for high seismic zones Cast-in-Place Concrete beam slab (FS10) is appropriate floor structural system for midrise building. Regarding foundation figure-7 shows that isolated foundation (F1) is 100% appropriate foundation system for low seismic Zones and Mat foundation (F3)-100%, Combine foundation (F2)-79% for high seismic zones, and it seems that Pile foundation (F4) is not suitable or not desirable floor structural systems in all zones. The study result also shows in figure-8 that for low seismic zone Cast-in-place Ordinary Moment Resisting Frame (L7) is 100%, but for high seismic zones Cast-in-place Concrete Special Moment Resisting Frame (L8) and Cast-in-place Concrete Ordinary Shear Wall (L9) are 100%, Cast-in-place Ordinary Moment Resisting Frame (L7) is 89% suitable Lateral Load Resisting system.

5. Conclusion

Structural system is an important system and has vital character for building enveloped. There are large number choices for structural system for building and their variations that can be selected for a particular project. Selection of appropriate structural system is effected by several factors and criteria. In this study development of appropriate structural system is covered for given properties and limitations. 42 questionnaires and 14 interviews were conducted with the design experts to find out the weights of limitation and constraints in use of various structural systems in Afghanistan. All the structural properties, weights of the limitation and score of the case studies were inputted in the model and exact results which match the case studies structural systems were obtained.

The finding of this study show most the limitation and constraints in the use of various structural systems and selection of an appropriate structural system for mid-rise building in Afghanistan.

a) A list and brief description of various factors has been prepared in this study which highly limits and constrains the usage of various structural systems in Afghanistan.
b) A list and brief description of various structural systems has been prepared in the study for reference and for usage in implementation of the model.
c) A model has been presented in this study to help in the selection of appropriate structural system for mid-rise building in Afghanistan. The analysis process method is based on the principles of Multi-criteria decision sport (Modified Analytical Hierarchy Process M-AHP).
d) A large number of factors effecting the selection of structural system for building have been identified and classified. Structural properties, Structural materials, Materials
e) Cost, Construction technology, Owner‘s Attitude, Wind loads, Earthquake excitation and Construction Time are those factors which have highly influence in the priority of the structural system selection.

The Current Practice of structural system for midrise building is not appropriate, this study result show isolated foundation, beam column and flat slab for low seismic and (combined or mat foundation, beam-column special frame and beam-Slab) structural system for high seismic zones.

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