# Study of Cost Effectiveness in Design of Structures with High Performance Concrete

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*Abstract:* **High Performance Concrete can be considered as a logical development of cement concrete in which the ingredients are proportioned and selected to contribute efficiently to the various properties of cement concrete in fresh as well as in hardened states. Higher strength is one of the features of High Performance Concrete which provides significant structural advantages. The three major components contributing to the cost of a structural member are concrete, steel reinforcement and formwork .This paper aims at comparing these major components when concrete of higher grade is used in the design and to establish that High strength concrete provides the most economical way for designing the load bearing members and to carry a vertical load to the building foundation through columns. The mix design variables affecting the concrete strength which are the most critical in the strength development of concrete includes water-cementations material ratio, total cementations material, cement-admixture ratio, amount of super plasticizer dose .These factors are to be analyzed in order to obtain a mix for concrete of higher grade. The design aid presently available gives design charts for design of members for concrete grade upto Fck=40N/mm².Design curves for Fy=250N/mm²,415N/mm² and Fck=60N/mm², Fck=70N/mm² using MATLAB have been drawn and given for aiding in the design of structures designed with these higher grade of concrete. Key Words: High Performance Concrete, High Strength Concrete.**

## I. INTRODUCTION

The use of high-strength materials is promoted in high-rise buildings to effectively use floor areas,control vibrations and expedite construction. The rapid increase in the cost of land in urban centers and availability of high-strength materials resulted in a significant increase in high-rise building construction. For instance, the United Arab Emirates has witnessed a large demand in high-rise buildings in recent years which led the designers to effectively utilize high-strength concrete and steel. Although the engineering understanding of the performance of high-strength reinforced concrete (RC) structures under static loading is well-developed, little information is available on the economics of high-rise buildings and their performance under earthquake loading. This emphasizes the need to investigate the behavior of high-rise structures when designed to different material strengths under the effect of earthquake loads which control the design of a wide range of tall buildings. The seismic performance of high-rise buildings is assessed in the present study through fragility relationships. Different approaches can be used to derive fragility functions (e.g. Rossetto and Elnashai 2005). The approach of generating damage data through analytical simulations is the most realistic option, particularly for the UAE, and hence it is adopted in the present study (Mwafy 2012). Several techniques for deriving vulnerability curves based on the numerically simulated structural damage statistics have been also proposed in the literature, with a diversity in structural idealizations, analysis methods, seismic hazard and damage models. Most of these techniques require a large number of analyses to account for uncertainty. This is particularly true when adopting multi-degree-offreedom inelastic dynamic simulations for deriving the vulnerability relationships, which is the approach adopted herein. The present study aims at investigating the relationship between seismic performance and cost-effectiveness of tall buildings through designing and developing detailed simulation models for high-rise buildings with various concrete grades, ranging from 45 to 110 MPa. The construction cost is compared in terms of steel, concrete and formwork. Over 1600 inelastic pushover analyses (IPAs) and incremental dynamic analyses (IDAs) are performed using 20 natural and artificial earthquake records to derive vulnerability relationships and to provide insights into the seismic response of the reference structures up to collapse.

## II BRIEF LITERATURE REVIEW

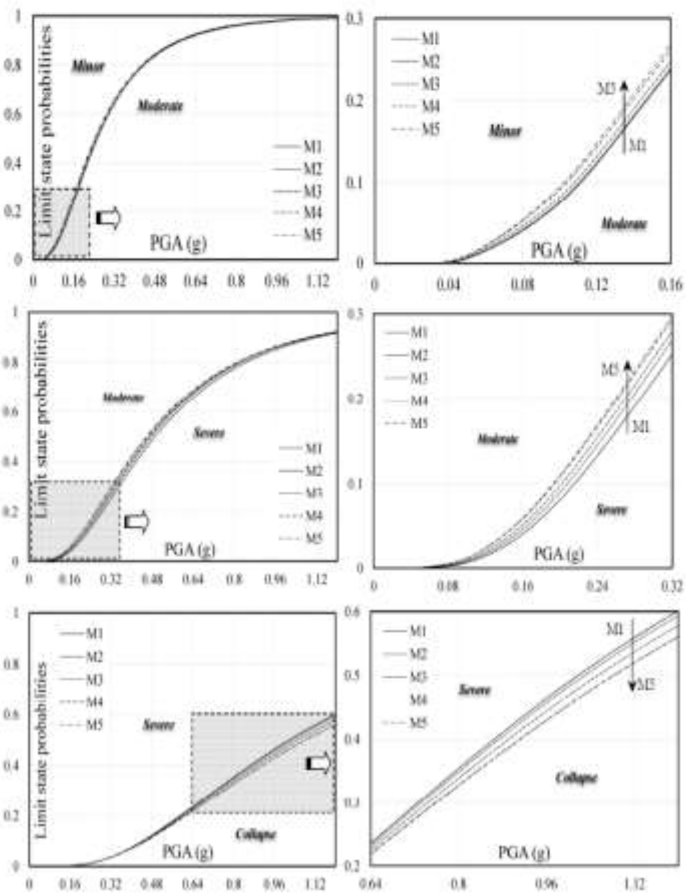
Beam - column joints have been recognized as critical elements in the seismic design of reinforced concrete frames (ACI 1999, AIJ 1990, Euro Code 1994, SNZ 1995).Numerous studies were conducted in the past to study the behaviour of beam-column joints with normal concrete (Shamim and Kumar 1999, Gefken and Ramey 1989, Filiatrault et al 1994). ACI- ASCE committee 352 (2002) makes recommendation on the design aspects of different types of beam-column joints, calculation of shear strength, and on reinforcement details to be provided (ACI 2002). These recommendations are however not intended for fiber reinforced concrete. Bakir (2003) conducted extensive research on parameters that influence the behaviour of cyclically loaded joints and has derived equations for calculating shear strength of the joints. A study conducted on fiber reinforced normal strength concrete by Filiatrault et al (1994) indicated that this material can be an alternative to the confining reinforcement in the joint region. The study conducted by Gefkon & Ramey (1989) illustrated that the joint hoop spacing specified by ACI-ASCE committee can be increased by a factor of 1.7 by the addition of fibers in the concrete mix. Jiuru et al (1992) studied effect of fibers on the beamcolumn joints and developed equation for predicting shear strength of joints for normal strength concrete. Bayasi and Gevman (2002) also experimentally proved the confinement effects of fibers in the joints reason and reduction in the lateral reinforcement by the use of fiber concrete. Besides these, there are several investigations on the effect of addition of fibers on the strength and durability of flexural members. Oh (1992) also indicated that the ductility and ultimate resistance of flexural members are increased remarkably due to the addition of steel fibers. ACI committee 544(1998) also reported considerable improvement in strength, ductility and energy absorption capacity with an addition of steel fibres.

## III. PERFORMANCE INDICATORS AND SCALING APPROACH

Three performance limit states are adopted in the present study for the derivation of vulnerability curves, namely: (i) Immediate Occupancy ‘IO’, (ii) Life Safety ‘LS’, and Collapse Prevention ‘CP’(ASCE 2006). The interstory drift ratio (IDR) is considered as the primary performance criterion to evaluate the damage states of the reference structures. For concrete wall structures, the three performance levels adopted by ASCE/SEI 41-06 (ASCE 2006) are 0.5%, 1.0% and 2.0%, which are related to minor cracking (IO), extensive damage (LS), and extensive concrete crushing and buckling. of reinforcement (CP), respectively. The code recommended drift limits tend to be on the conservative side. Less conservative IDRs have been recommended in the literature based on analytical and experimental results. For instance, for ductile concrete wall structures, Ghobarah (2004) proposed IDR limits associated with ‘no damage’, ‘light reparable damage’, ‘irreparable damage or yield point’, ‘severe damage or life safe’, and ‘collapse’ to be <0.2%, 0.4%, >0.8%, 1.5%, and >2.5%, respectively. Following these recommendations, a CP performance level of 2.5% is therefore adopted in the present study.To estimate the above stated IO and LS performance limit states, IPAs are conducted for the five reference structures to trace the sequence of yielding and the progress of the capacity curve up to the collapse limit state. Following the recommendations of modern design guidelines, two lateral load distributions are employed in IPA, namely the uniform and the inverted triangular load patterns (ASCE 2006). Previous studies on high-rise buildings concluded that the uniform lateral load can be conservatively used for estimating the initial stiffness and lateral capacity (e.g. Mwafy et al. 2006; Mwafy 2011). For a building to be occupied immediately after the earthquake with little or no repair, it should remain in the elastic range so that non-structural components are not significantly damaged. First yield is typically assumed when the strain in the main longitudinal tensile reinforcement exceeds the steel yield strain. The IDRs at the first indication of yield is considered as the IO limit states. The adopt IO performance limit are 0.77%, 0.78%, 0.78%, 0.78% and 0.79% for the M1 to M5 buildings, respectively. These are the most conservative values obtained from both IPAs and IDAs. The LS limit state, which falls between the IO and CP, represents a ‘significant damage’ sustained by the structure, while it accounts for a reasonable margin of safety against collapse. This margin is considered in ASCE/SEI 41-06 (2006) as 50% of the CP limit state. In the present study, the starting point of the post-elastic branch (global yield threshold) is considered as the LS limit states. This value is 1.35%, 1.32%, 1.30%, 1.28% and 1.27% for the M1 to M5 buildings, respectively. The adopted IO, LS and CP limit states are generally consistent with previous studies. On the basis of the adopted limit states, extensive IDAs are performed with 20 natural and artificial ground motions to derive the fragility curves as described in the following sections. The choice of a measure for ground motion intensity is important for the accurate representation of the statistics along the horizontal axis of the fragility curve. Several intensity measures were recommended in previous studies such as Peak Ground Acceleration (PGA) and Spectral Acceleration (SA). The selected ground motions represent certain seismic scenario. Scaling these ground motions using their PGAs relates the seismic forces directly to the input accelerations. This simple scaling method agrees with the approach adopted by design codes, and hence it was employed in several previous studies and in the present work (e.g. Kwon and Elnashai 2006). The selected input ground motions are scaled using their PGA to derive vulnerability relationships based on the expression proposed by Wen et al. (2004). The IDAs are carried out for all reference structures up to the satisfaction of different limit states. Each of the 20 input ground motions is scaled up using an incrementing scaling factor of 0.08g, which represents half the design PGA according to the study of Mwafy et al. (2006). Fifteen time history analyses are conducted for each building-input ground motion, starting from a PGA of 0.08g and ending with a PGA of 1.20g, to attain all limit states and improve the resolution of the vulnerability curves, as shown in Figure.

## IV. DERIVATION OF FRAGILITY RELATIONSHIPS USING IDA

Vulnerability relationships of the five reference structures are derived using IDAs under the effect of the 20 natural and artificial ground motions. Local and global response parameters are monitored throughout the scaling range (0.08g to 1.20g), as discussed above. A total of 300 points are plotted for each reference building, each point represents a PGA-IDR value obtained from an inelastic response history analysis. Regression analyses are carried out to derive the power law equation required for deriving the fragility relationships. Figure 8 depicts a sample of IDA results for building M5. The statistical distributions obtained from the over 1500 IDAs carried out for the five reference structures are used to calculate the probability of exceeding each limit state at different intensity levels. The vulnerability curves are derived by plotting the calculated probability data versus PGAs. Figure shows the derived fragility relationships of building M5, while Figure 9 compares between the fragility curves of the reference structures at different limit states using the methodology outlined above.




## V. CONCLUSIONS

This paper investigated the impact of increasing material strength on seismic performance and cost effectiveness of high-rise buildings. The study included the structural design and numerical modeling of five 60-story structures representing contemporary high-rise buildings with varying concrete strengths, ranging from 45 to 110 MPa. The comprehensive structural design and detailing of the reference structures to the most recent building codes insured that almost equal periods of vibration were obtained for all buildings. This enabled the effective assessment and comparison of seismic performance and cost from different designs. Over 1600 inelastic pushover analyses (IPAs) and incremental dynamic analyses (IDAs) were carried out using detailed fiber-based simulation models and 20 earthquake records. Limit states were selected based on local and global response and used to derive the vulnerability relationships of the reference structures. The statistical distributions obtained from IDA results were used to calculate the probability of exceeding different limit states at different ground motion intensity levels. Increasing the concrete strength generally results in the most cost effective design due to the reduction in section sizes and increasing saleable area. The total profit gained from using the highest material strength was $4.77 million when compared with the building that has the lowest concrete strength. The net profit, which was calculated from saleable area after deducting all construction expenses and cost of land, consistently increased with increasing concrete strengths. The seismic performance of the five reference structures was comparable and acceptable at both the design and twice the design PGA. Some damage states slightly increased with increasing material strength, particularly at lower PGA levels, while other damage states slightly decreased. Monitoring the local response confirmed that the minor increase of certain damage states did not cause any undesirable consequences in vertical members. It was concluded that the behavior of high strength concrete structures is not inferior, and may exceed at high ground motion intensity levels, that of normal strength materials. The overall improvement in profit-performance from increasing concrete strength exceeded 10%, which is significant considering the total value of high-rise buildings.

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