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Prefabricated multistory SAPE publicizing seismicity using SAP

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Abstract :

The paper investigates the inelastic seismic response of current multi-tale bolstered Concrete (RC) homes to a quantity of seismic situations applicable to medium seismicity regions of the middle East. 4 RC buildings are taken into consideration, representing ordinary and irregular ductile second-Resisting frame (MRF) structures. these are designed and exact in step with layout provisions hired in this area. A validated analytical device and delicate fiber modeling technique capable to simulate the cyclic reaction of structural participants are followed. The seismic reaction from considerable dynamic crumble analyses is monitored on the member and the structure tiers for a numerous set of input floor motions. Investigating the inelastic reaction of the buildings designed to the 2 layout provisions provides insight into the conduct of systems designed to extraordinary levels of pressure reduction elements. It additionally offers global calibration to the country wide layout codes inside the vicinity and aids in information the variations and similarities with international design provisions. This enables to enhance the design codes, which is the handiest mean to lessen earthquake losses and increase public safety.

keywords: Prefabricated, Multistory shape, exposure, Engineering Seismicity, SAP

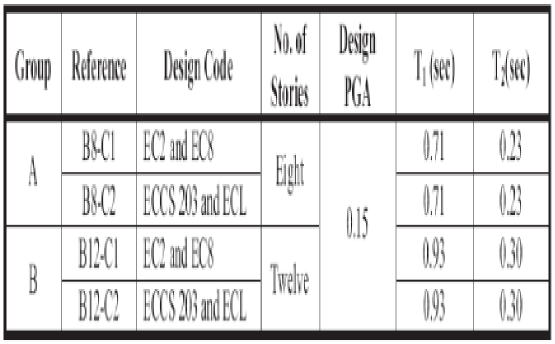
1. INTRODUCTION

The lack of reliable design codes that account for the latest technology and deep experience alongside local construction practice and simplified requirements has a profound influence on the large human and economic losses observed from recent earthquakes of 2005 Kashmir (Pakistan) and 2006 Yogyakarta (Indonesia). These events have clearly demonstrated the potential for a major catastrophe from future earthquakes, which may hit even more densely populated and industrialized regions than the affected regions (e.g. Durrani et al., 2005). Inadequate design of buildings significantly increases their vulnerability to earthquake damage. Structures which are properly designed on the basis of well-calibrated and extensively verified seismic codes are less vulnerable as a result of their efficient energy dissipation systems. Modern seismic codes and guidelines (EC8, 2004; ASCE, 7, 2005) have been developed based on extensive research related to specific regions and observations of actual damage that has occurred to structures in past events. The continuous update of design codes in the Middle East requires extensive research to calibrate the design provisions and assess the seismic performance of contemporary buildings to mitigate potential earthquake-related losses. The European codes for design of concrete structures (EC2, 2004) and design of structures for earthquake resistance (EC8, 2004) are currently the official standards for design of RC buildings in different countries in Europe. EC8 adopts a trade-off between strength and ductility by allowing designing to three progressive ductility levels, with increasing capacity design requirements. These standards represent state-of-the-art design provisions, which may be applied to different regions with diversity in structural systems, seismicity and construction techniques. On the other hand, the 2001 version of the Egyptian code for design and construction of concrete structures (ECCS 203, 2001) and the Egyptian code of loads (ECL, 2003) represent typical design provisions adopted in the Middle East. ECCS, 203 has been updated to enhance the ductility by adopting the concept of capacity design. ECCS, 203 also adopts different levels of reinforcement detailing: (i) structures located in the lowest seismic zone are designed and detailed without additional requirements and (ii) structures located in medium and high seismic zones are designed, dimensioned and detailed either as non-ductile or as ductile, with additional provisions to improve ductility.

2. STRUCTURAL DESIGN AND ANALYTICAL MODELING

Four RC buildings were selected in the current study to represent characteristics of contemporary medium-rise RC buildings designed to modern seismic codes. The buildings are split into two sets based on their configuration, as shown in Table 1. Within each group, a pair of buildings is considered, representing two different designs. The two configurations are for a twelve story regular frame building and an eight story irregular MRF structure. All beam crosssectional dimensions are 0.3 0.6 m, while they are 0.3 0.8 m in the ground floor of the 8-story building. Column crosssections are identical throughout the buildings height.

Table 1. Characteristics of the Four Structural Systems Investigated



Group	Reference	Design Code	No. of Stories	Design PGA	T_1 (sec)	T_2(sec)
A	B8-C1	EC2 and EC8	Eight	0.15	0.71	0.23
	B8-C2	ECCS 203 and ECL			0.71	0.23
B	B12-C1	EC2 and EC8	Twelve		0.93	0.30
	B12-C2	ECCS 203 and ECL			0.93	0.30

Two of the four investigated buildings (B8-C1 and B12-C1) were designed and detailed in accordance with Eurocode 2 and 8, which represent typical modern seismic codes applicable to more than one country with various levels of seismicity and soil conditions. The selection of this group of buildings was motivated by the desire to include in the study a sample of structures carefully designed and detailed to the modern design practice. The buildings were designed and detailed to the medium ductility requirements of EC8.The design PGA is 0.15g, the soil is medium class (C) and the importance factor is 1.0.The permanent and live loads are 5.5 kN/m2 and 2.0 kN/m2, respectively. The total gravity loads used in seismic analysis are 36600 kN and 22680 kN for the 12 and the 8-story structure, respectively. The crosssection capacities were computed by for concrete and a characteristic yield strength of 500 N/ mm2 considering characteristic cylinder strength of 25 N/mm2 for steel. (Table.1. & Figure.1).

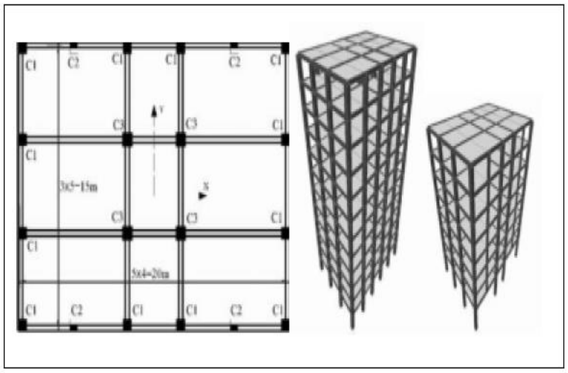


Figure.1. Description Of The Investigated Building

On the other hand, the design of B8-C2 and B12-C2 buildings were carried out using ECCS 203 and ECL. The concrete strength is 25 N/mm2 and steel strength is 400 N/mm2. Proportioning of structural members was carried out using the seismic provisions of ductile frames adopted by ECCS 203. All ductility requirements of ECCS 203 were taken into consideration, including the capacity design provision for columns. The concrete strength used is 25 N/mm2, while a steel strength of 400 N/mm2 was selected since the steel S500 used in design of the European buildings is neither available in the local market nor recommended by the Egyptian code. Member cross-sections are identical for the pair of buildings of the same height to allow comparisons of the response of buildings designed to different design provisions. Figure shows column and beam sizes and reinforcement details of the two buildings designed to ECCS 203 and ECL. Elastic free vibration analyses of the investigated buildings confirm that the non-cracked fundamental periods of the buildings (0.71 - 0.93) cover a realistic range of medium-rise multi-story buildings, as shown from Table 1.Different building heights (25.5 - 36 meters) and degree of regularity were also taken into consideration to insure that the assessment sample represents contemporary medium-rise RC building.

2.1 Seismic Conventional Design

Many building collapses during earthquakes may be attributed to the fact that the bracing elements, e.g. walls, which are available in the upper floors, are omitted in the ground floor and substituted by columns. Thus a ground floor that is soft in the horizontal direction is developed (soft storey). Often the columns are damaged by the cyclic displacements between the moving soil and the upper part of the building.

Figure. 2 Seismic Conceptual Design and Capacity Design

Basic principles for the seismic design of buildings

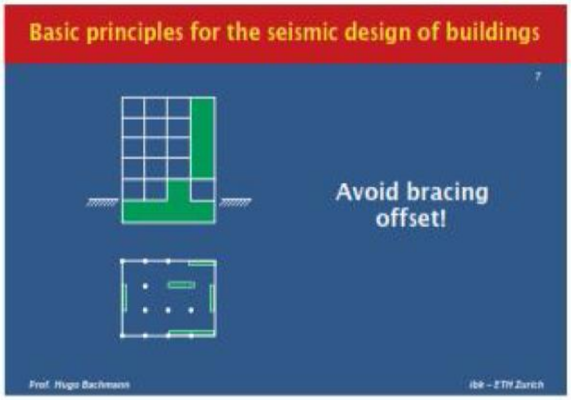
Avoid soft-storey ground floors!

Prof. Hugo Bachmann

ibk - ETH Zurich

Figure. 3 Principles for the Seismic Design

2.2 Avoid Bracing Offsets



Basic principles for the seismic design of buildings

7

Avoid bracing offset!

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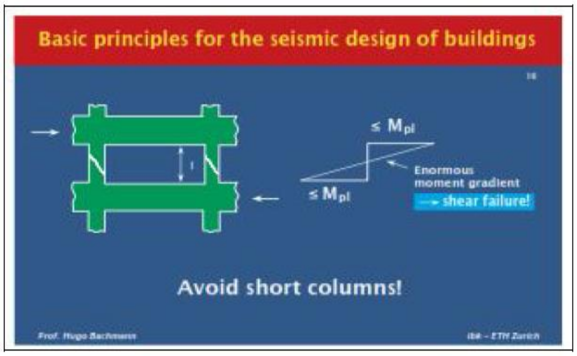
Figure. 4 Horizontal Bracing Offsets

Horizontal bracing offsets, in plane (at the bottom of the plan figure) or out of plane (at the top of the plan figure), result when the position of the bracing changes from one storey to another. The bending moments and the shear forces induced by the offset cannot be fully compensated, despite substantial additional costs. The offsets disturb the direct flow of forces, weaken the resistance and reduce the ductility (plastic deformation capacity) of the bracing. Moreover, they cause large additional forces and deformations in other structural elements (e.g. slabs and columns).Compared to bracings that are continuous over the height of the building, bracings with offsets increase the vulnerability of the construction and usually noticeably reduce its seismic resistance. Bracing offsets must therefore be absolutely avoided.(Figure.4)

2.3 Avoid Short Columns



Basic principles for the seismic design of buildings

$\leq M_{pl}$

Enormous moment gradient

→ shear failure!

$\leq M_{pl}$

Avoid short columns!

Prof. Hugo Bachmann

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Figure.5 Short Column Indication

The shear failure of so-called «short columns» is a frequent cause of collapse during earthquakes. It concerns squat columns, i.e. columns that are relatively thick compared to their height, and are often fixed in strong beams or slabs. Slender columns can be turned into short columns by the addition of parapet in fills in frame structures («unintentionally shortened columns»). Columns under horizontal actions in frame structures may be stressed up to their plastic moment capacity (plastification or failure moment). In the case of short columns with considerable bending capacity, an enormous moment gradient and thus a large shear force results. This often leads to a shear failure before reaching the plastic moment capacity. Short columns should therefore be avoided. An alternative is to design and detail the columns in accordance with the rules of capacity design, whereby the shear capacity must be increased to account for the over strength of the vertical reinforcement (Figure.5).

3. INELASTIC RESPONSE OF BUILDINGS

The capacity envelops of the four buildings obtained from inelastic pushover analysis using an inverted triangular lateral load distribution. Mwafy and Elnashai and Mwafy concluded that this lateral load pattern results in a conservative estimate of initial stiffness and ultimate capacity of medium-rise buildings. This is unlike those designed to EC8, which imposes an upper limit on the R factor (behavior factor) of 3.9 for frame systems. EC8 also recommends reducing the R factor by 20% for irregular buildings in elevation. This results in a large difference between the design forces and hence the capacities of the buildings designed to the two seismic codes. The sequence of formation of plastic hinges in the external frame columns of B8-C2 and B12-C2 is also depicted in Fig. These external frames are more vulnerable than internal systems as a result of the higher stiffnesses of their beams, which attract higher seismic forces. This sequence is comparable for the pair of buildings of the same configuration. Although first yielding is observed in beams of the four structures, the unfavorable concentration of plastic hinges in the planted columns of the irregular buildings is unfavorable. No indication of a hinging mechanism is detected in the four buildings, even in the soft story of the irregular structures (B8-C1 and B8-C2). The results confirm that ductile frames adequately designed to EC2 and EC8 as well as ECCS 203 and ECL have adequate strength and ductility, and are not likely to develop a collapse mechanism. This is mainly due to the adoption of the capacity design provisions by the design codes.

The dynamic response of the buildings is investigated by performing a series of inelastic response history analysis using the progressively-scaled input ground motions mentioned above. For the sake of brevity, only sample results from these extensive analyses are presented for the buildings at various intensity levels. Table shows the local and global response of B8-C2 and B12-C2 for sample records. The variability of the inelastic response is quite significant under different input ground motions. This is more observable when comparing the two seismic scenarios investigated (natural and artificial records), which match two different design spectra. Clearly, the amplification of the artificial records at the period range of both the investigated buildings is higher than the natural records, which results in higher response. Summary of the response of B8-C1 and B12-C1 from four artificial records matching the design spectrum Type (II) is studied with the results of the incremental dynamic collapse analysis of the four buildings.

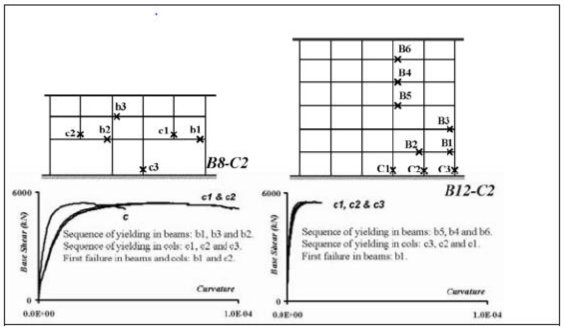


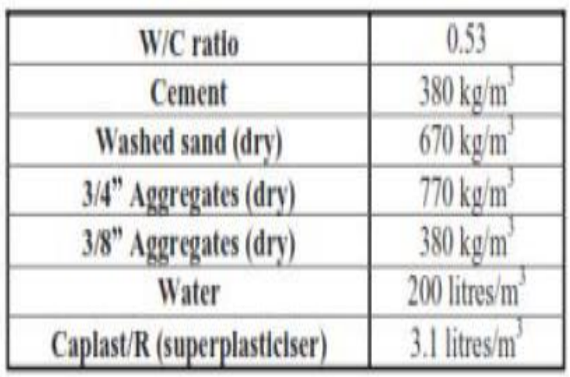
Figure.6 Sequence of Yielding and Curvature Demands In Beams and Columns of B8-C2 and B12-C2

It is clear that the response of B8-C2 is perfectly elastic while few plastic hinges in beams are observed in B12-C2 under the most probable seismic scenario (natural records).Yielding is observed only in beams under the conservative seismic scenario of the artificial record. At twice the design ground motion, plastic hinges are observed in beams, cutoff columns and at the base of the main columns. With the exception of the cut-off vertical members, yielding in main columns is only observed at the ground level, even under the most conservative seismic scenario. Disadvantages of irregular structural systems are clearly exemplified when comparing response of the irregular buildings with the regular systems. However, since capacity design protects the main columns and prevents any formation of collapse mechanism, the response of both the B8-C2 and B12-C2 buildings is considered satisfactory (Figure.6).

4. MATERIALS AND SAMPLE PREPARATION

The concrete mix contains fine aggregate which is dry local washed sand, virgin coarse aggregate which is dry Gabro aggregates of sizes 3/4 in. and 3/8 in. brought from the United Arab Emirates. The recycled coarse aggregate is chunks of demolished concrete that were crushed to sizes 3/4 in. and 3/8 in. The water used is cold tap water. The admixture in the mix is Caplast/R which allows lowering of the water-cement ratio (w/c) while keeping the workability unchanged. It was bought from local materials four different mixes were designed with a target water-cement ratio of 0.53, except for Mix. No 4, as shown in Table.2 Two of the mixes were control mixes and the other two mixes were developed by keeping all the mix design parameters constant except for company the aggregate constituents.

Table 2 Mix Quantities Used in the Standard Reference Mix (Kg/M³)



W/C ratio	0.53
Cement	380 kg/m^3
Washed sand (dry)	670 kg/m^3
3/4" Aggregates (dry)	770 kg/m^3
3/8" Aggregates (dry)	380 kg/m^3
Water	200 litres/m^3
Caplast/R (superplasticiser)	3.1 litres/m^3

4.1 Flexural Strength Testing And Results

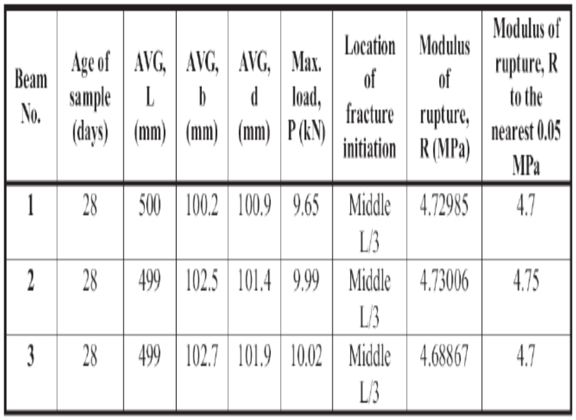
The modulus of rupture is defined as the flexural tensile stress at which a crack forms in plain concrete beams. The flexural test, determines the modulus of rupture. A plain concrete beam is loaded at the third point at a rate of 0.5 KN/Sec. Figure 1 shows the third point loading in this test. When the beam fails due to tensile stresses produced from the bending moment (failure immediately follows the formation of tensile cracks) the modulus of rupture (tensile strength) is calculated. Figure 2 shows the test apparatus and a tested sample beam. The equation used to calculate the modulus of rupture is in accordance with the ACI specifications 78-94 in this regard as follows:

$$R = PL / pd$$

where:
R: modulus of rupture, MPa;
P: maximum applied load, N;
L: spam length (m);
b: average width (m);
d: average depth (m);

The span length, width and depth of each beam were measured at three different locations of the beam. The average values were used in Eq. (1) above. The tests were performed based on 28-day strength of the concrete. Three beams from each of the four mixes were tested. Tables 4, 5, 6 and 7 show the results for mixes 1, 2, 3 and 4 respectively. Table 3 summarizes the results of all the tested beams. The results were analyzed using ANOVA1 (MATLAB 2002).

Table 3 Mix No. 1 Day 28 With 100% Recycled Aggregate



Beam No.	Age of sample (days)	AVG, L (mm)	AVG, b (mm)	AVG, d (mm)	Max. load, P (kN)	Location of fracture initiation	Modulus of rupture, R (MPa)	Modulus of rupture, R to the nearest 0.05 MPa
1	28	500	100.2	100.9	9.65	Middle L/3	4.72985	4.7
2	28	499	102.5	101.4	9.99	Middle L/3	4.73006	4.75
3	28	499	102.7	101.9	10.02	Middle L/3	4.68867	4.7

The average modulus is 4.2 MPa. From Figure.7 it can be seen statistically that the modulus of rupture for the four mixes is at a 5% level of significance. The ACI code (American Concrete Institute, 2002) states that the flexural strength of concrete is 10 to 15 % of the compressive strength. The target compressive strength for the mixes is 30 MPa (AlKhaleefi, 2006). In Table 8 the average flexural strength for each mix is within the ACI range.

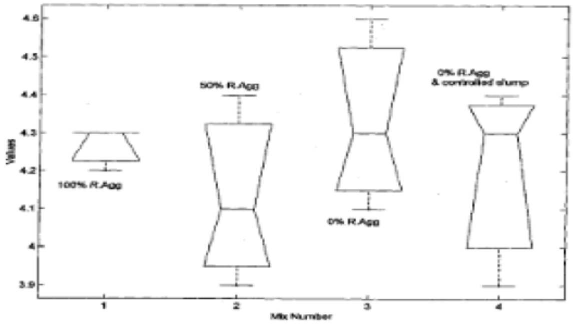
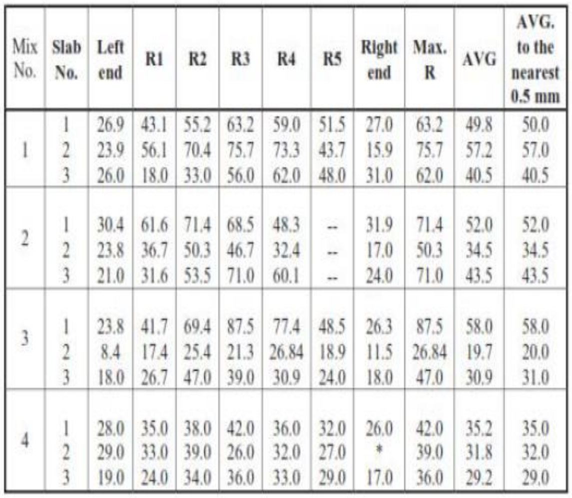


Figure.7 Modulus Of Rupture (Mpa),P=0.7278

4.2WATER PENETRATION TESTING AND RESULTS

The ease with which water can pass through the concrete is defined as permeability. The absorption is defined as the ability of concrete to draw water into the voids. Concrete tends to be porous when air voids are not removed during compaction. For fully compacted concrete the permeability decreases with decreasing water-cement ratio. The permeability is also influenced by the fineness and the chemical composition of the cement. Coarse cements have the tendency to produce pastes with relatively high porosity. Aggregates with low porosity have significant effect on the permeability of the concrete. Also, when the constituent materials of the concrete are segregated this will have adverse effect on the permeability and consequently the strength of the concrete. The German Method was used in the water permeability tests. Three slabs 200x200x120 mm in dimension from each of the four mixes were cast. After being cured for 28 days in room temperature water tanks, each sample was placed in the machine. Water was then released upwards from under the sample at a certain pressure for a fixed time period. Each sample was placed at a pressure of 1 bar for 24 hours and then 3 bars for 48 hours followed by 7 bars for 24 hours. The samples were split open thereafter. The distance travelled upwards by the water inside the concrete was taken at different locations. The average for each sample was calculated for comparison and listed in table 10. ANOVA1 was used to analyze the averages. Table.4 4 shows the results. Figure. 8 shows Permeability Test: Distance Travelled Up In the Concrete (mm) p=0.3438.

Table 8 Results of Water Penetration of the Mixes (mm)



Mix No.	Slab No.	Left end	R1	R2	R3	R4	R5	Right end	Max. R	AVG	AVG. to the nearest 0.5 mm
1	1	26.9	43.1	55.2	63.2	59.0	51.5	27.0	63.2	49.8	50.0
	2	23.9	56.1	70.4	75.7	73.3	43.7	15.9	75.7	57.2	57.0
	3	26.0	18.0	33.0	56.0	62.0	48.0	31.0	62.0	40.5	40.5
2	1	30.4	61.6	71.4	68.5	48.3	--	31.9	71.4	52.0	52.0
	2	23.8	36.7	50.3	46.7	32.4	--	17.0	50.3	34.5	34.5
	3	21.0	31.6	53.5	71.0	60.1	--	24.0	71.0	43.5	43.5
3	1	23.8	41.7	69.4	87.5	77.4	48.5	26.3	87.5	58.0	58.0
	2	8.4	17.4	25.4	21.3	26.84	18.9	11.5	26.84	19.7	20.0
	3	18.0	26.7	47.0	39.0	30.9	24.0	18.0	47.0	30.9	31.0
4	1	28.0	35.0	38.0	42.0	36.0	32.0	26.0	42.0	35.2	35.0
	2	29.0	33.0	39.0	26.0	32.0	27.0	*	39.0	31.8	32.0
	3	19.0	24.0	34.0	36.0	33.0	29.0	17.0	36.0	29.2	29.0

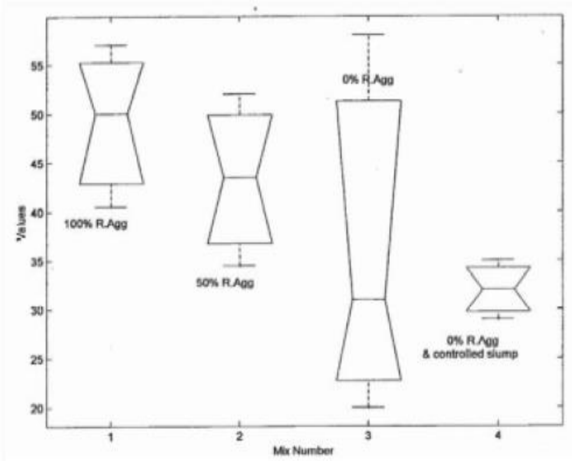


Figure. 8 Permeability Test: Distance Travelled Up In the Concrete (mm) p=0.3438.

5. ANALYSIS AND DESIGN OF HIGH-RISE BUILDINGS

The main concern of this paper is to provide an overview of the current analysis and design methodology for reinforced concrete high-rise buildings. A case study of residential complex consisting of two new 30-floor towers located in Kuwait city is presented to demonstrate the most significant factors to be considered to ensure the building is designed to have sufficient strength to withstand ultimate (factored) gravity (dead plus live) and lateral (wind plus seismic) loading and sufficient stiffness to limit deformations and lateral drift to be within the acceptable range to verify the occupancy comfort level. Building code procedures based on general assumptions, are usually but not always conservative, and do not provide accurate wind loads because of exposure conditions, directional properties of the wind climate, complex geometry shapes, torsion, aerodynamic interactions, and load combinations.

5.1 Proposed New Structure

The new structure will comprise two 30-storey towers and commercial shops within the plot. One of the new towers shall be used for residential apartments and the other one for serviced (hotel) apartments. Due to the restricted size of the site, together with municipality set-back regulations these towers will be in close proximity to the existing buildings. The locations of these new towers in plan are selected to allow for maximum outward gulf views and inward natural light, while maintaining privacy. The tower elevations are designed to be integrated with the existing buildings elevations. A strip of 800mm fair face concrete is maintained in each floor level and the rest of the floor height is used as stone cladding for both towers to match with the existing buildings. Each tower is serviced by a mechanical floor located at the 19th floor. The architects and engineers worked hand in hand to develop the building form and the structural system, resulting in towers that efficiently respond to the wind, while maintaining the integrity of the design concept. Figure 1 shows a perspective view of the new towers and the existing buildings. The slenderness ratios of the new towers are about 8-to-1 for tower (A) and 4-to-1 for tower (B) due to the very limited space available. The partial demolition of the existing basement and ground structure shall be required to allow for the new construction works. The demolition line in the foundation level is selected to be within the settlement strip while the same in the podium level is selected to be within the existing expansion joints location. This helps to keep the structural stability of the remaining part of the structure unaffected by the demolition works.

6. CONCLUSION

The study assessed the seismic performance of two sets of contemporary RC buildings designed and detailed to two design provisions commonly used in design in the Middle East, namely the European and the Egyptian codes. Designing the same structure to different force reduction factors (R) were exemplified in the investigated case studies since the above-mentioned codes adopt different R factors. Four RC buildings were designed and extensively analyzed using a refined fiber modeling approach and a verified analysis tools. Inelastic pushover and incremental dynamic collapse analyses were undertaken for the four buildings using a diverse set of synthetic and natural ground motions scaled using the spectral intensity scale.

- The higher design strength of the European buildings, which leads to attracting higher seismic demands and
- The higher contribution of gravity loads in design of the investigated structures compared with seismic actions. As intended by the capacity design provisions, inelasticity was observed only at the ground story columns, with acceptably few exceptions in the cut-off columns of the irregular buildings.
- The comparative study presented in this paper confirmed the adequate safety margins of buildings designed to the latest design provisions. It is therefore highly recommended to adopt the ductility and capacity design requirements of modern seismic codes in design of multi-story buildings, which would render these structures to be more reliable and provided with efficient seismic-resistant mechanisms.

Seismic retrofit of RC-MRFs is a difficult task for structural engineers. This comes from many reasons such things as lack of knowledge of the existing structures, difficulties in assessing their seismic performance, in selecting and designing the appropriate seismic retrofitting strategies and systems. In this study, many seismic retrofitting systems to date have been summarised. Amongst those, Restrained Buckling Braces and Eccentrically Brace Frames have advantages over the other systems thanks to their capacity in obtaining a better hysteretic behaviour under seismic actions: stable hysteresis loops in both tension and compression without much degradation in stiffness and strength. However, the others, such as shear walls made from steel, aluminium or reinforced concrete or Concentric Conventional Braces, also have their own advantages, mostly based on their capacity in more or less increasing the stiffness and strength, in absorbing the seismic energy and in low price of fabrication.

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