Architectural and Structural Design of Earthquake Disaster Management Multi-Purpose Complex (EDMMC) Based on Suspension and Isolation

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SUMMARY
Since the construction of Earthquake Disaster Management Multi-purpose Complexes (EDMMC) with self-help neighbourhood approach should be mentioned as one priority in large cities like Tehran, in this paper, architectural and structural design of proposed similar EDMMCs for different districts is explained. Special structural alternative should be adopted for the complicated architectural form which is deemed to cover diverse cervices of a mixed-use building before, during and after an earthquake. For this purpose innovative architectural form is proposed based on the structural-seismic principles of suspension and isolation which are inspired by the new seismic concepts of discontinuity, movability and flexibility. Innovative alternatives allow for the complex to have open spaces safely designed for architectural purposes and suspended parts to laterally move over the fixed part during a severe earthquake. Seismic performance of this special building is evaluated using nonlinear time-history analysis with various records covering diverse range of frequency contents for far and near fields earthquakes to ensure that the structure remains operational (immediate occupancy level) after a severe earthquake. The present work can show that complicated architectural form can be safely designed if new seismic concepts are considered during the form generation procedure.

Keywords: earthquake disaster management multi-purpose complex, suspension, isolation, innovative seismic concepts

1. INTRODUCTION

This has been learnt from past earthquakes that there is always a time delay in presence of rescue and relief teams after earthquake in large and populated cities and therefor the role of local people (neighbors) as the first rescue team is important [1]. So to achieve a powerful community-based disaster management, self-help neighborhood capabilities should be increased. The concepts and principles of community-based disaster risk management (CBDRM) and self-help neighborhood have been already investigated, [1]. The idea of earthquake disaster management multipurpose complex (EDMMC) with self-help neighborhood approach has been proposed for making community-based disaster management feasible in each district of a large city like Tehran. The EDMMC as it can be understood from its name can have different functionalities before and after earthquake. In fact they can be used not only for providing the local people in each area with the required tools and facilities for self-help in emergencies, but also they can be centers for several activities related to CBDRM. An EDMMC requires special architectural and consequently structural design. This paper discusses architectural and structural design of a proposed EDMMC for the city of Tehran based on new concepts in which the architectural needs of the complex satisfy by the new structural concept based on new seismic means.

2. POSSIBLE FUNCTIONS OF "EDMMC"

The EDMMC have several functions before, during and after the earthquake which includes;

Before earthquake:
- Theater, conference and meeting hall
- Exhibition
- Grocery shop
- Drug store
- Shopping center
- Café and restaurant
- Educational base (e.g. for increasing preparedness of local people against earthquake)

After earthquake:
- Temporary occupation
- Emergency hospital
- Food and drug storage place
- Psychological consultancy (for whom have lost their family or faced financial damages)

Permanent:
- Information and communication technology (ICT)
- Disaster management meeting center
- Emergency tools and machines

In fact the EDMMC acts as a mixed-use building with different services before, during and after an earthquake. To have all these functions working with highest possible performance, a special architectural, structural and seismic design is required to facilitate self-help neighborhood affairs. For such a new idea and to cover various complicated functions and vital role especially after earthquake, innovative and probably complicated architectural scheme is needed. The new and complicated architectural scheme needs an innovative structural alternative. The seismic safety is certainly very important because of the vital importance of the complex. The key note for the design process is that the structural system and seismic alternatives should conform to architectural form. This needs a great collaboration of structural engineer and architect who both are familiar with CBDRM and the role of EDMMC in reducing earthquake bad impacts.

3. SITE SELECTION

EDMMC should be located in an easy-access area of the neighbourhood and centre of gathering of local people so that it is easy for everyone to know and get there. Decision should be made based upon special site risk analysis from seismic and geotechnical points of views.

4. CONSIDERATION IN ARCHITECTURAL DESIGN

In addition to codes' limitations for architectural design of buildings in seismic prone areas like simplicity and symmetry, regularity in plan and elevation, having a proper aspect ratio and being not very long or large in plan and recommendations like avoiding complex configuration, using dividable plan shape, seismic joints, lightweight materials and horizontal expansion [2], Architecture of an EDMMC needs a good insight in disaster management, multipurpose architecture principles in addition to seismic consideration. Below is a list of special architectural features of these complexes;

- Preferably being low-rise
- If possible having a large yard and/or large gathering hall (for the function of emergency shelter as well as emergency hospital)
- Gathering hall should not be stepped and it is recommended to be placed on the ground floor
- Well-equipped with telecommunication services
- Equipped with emergency electric power generator as well as water storage system
- Interior design, non-structural equipment design (making potential for places, devices, equipment and materials inside to be deployable when needed, e.g. removable partitions)
- using light weight nonstructural components and with minimum total volume with safely installation equipment
- Light weight façade

5. DESIGN PROCESS, INNOVATIVE CONCEPTS, STRUCTURE AND ARCHITECTURE INTERACTION

The EDMMC is deemed to be built in each district of the city of Tehran and because of highly congestion of buildings and lack of free land, the decision made to use the height to cover all required functions. To achieve the best performance from both seismic and architectural points of view, two important points need to be given consideration at the first step of the design:

1. Type of seismic resistant devices; for the passive or hybrid devices to work with their best potential and overall structure cost, special morphological strategies should be adopted [4].
2. Theater hall at the ground floor; since the theater hall should be served as temporary occupation after the earthquake, it should be free-of-column and placed at the ground level. This make the structural design process more challenging because of the obligation of four additional stories above the ground level.

The proposed alternatives consists of suspension of stories with other functions above the theater hall roof so that all gravity loads are carried by hangers from bottom to top working in tension and then transferred to three lines of column located at above and besides of theater hall, (figure 1). The above columns are placed at the most resistant part of the theater hall roof. The alternative allows the sloped roof of the theater hall to carry relatively less gravity loads, also large columns are replaced by small hangers thus reaching more efficiency in articulation of spaces. All connections of the suspended stories and compression columns are moment resistant to resist against wind load in every directions (parts of gravity load is directly carried by compression columns). For this high-importance complex, the seismic resistant system had been already opted to use seismic isolation and thus the global configuration was designed based on special seismic design principles for isolated structure which directly affect the architectural form. Since suspension can meet the principle of discontinuity and discontinuity is an important principle of new seismic protection systems like seismic isolation, isolation of all compression lines is opted as the best seismic alternative so that the suspended stories can move over the fix part (theater hall) during a severe earthquake. The open ground floor can now be safely created. As it can be seen form the preliminary concept for architectural design, the innovative seismic principles of discontinuity and motion are integrated into architectural form generation process and directly affect the structural configuration. The gap between two separated structures can be filled with energy dissipative devices.

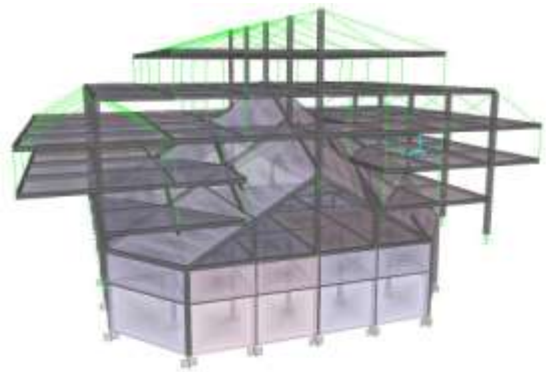

Figure 1: final architectural form, structural configuration

Architectural form generation process carrying structural concept is schematically shown in figure 2.

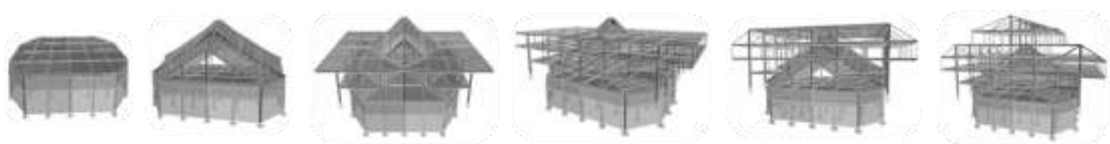

Figure 2: architectural form generation process based on structural-seismic concepts

The process of architectural form generation could be briefly explained for the complex:

- Emergency priority reduction as height increases:

The priority of emergency and consequently ease of access forces to create a free-of-column space at the ground level as emergency and temporary accommodation. On this basis emergency hospital and drug storage space are given second priority of emergency. Food storage, psychological consultancy get third priority and ICT and management get fourth priority. Since almost all spaces should be flexible in function before and after the earthquake, the most closet function for this space was selected as theatre and conference hall which should has high and sloped roof. This situation yields need for special structural alternative to safely accommodate four stories above.

- Suspension of upper stories:

With suspension of upper stories by cable heavy gravity load is directly transferred to the ground by 2 line of side column.

- Isolation of suspended part:

One line of column should have been added to the most resistant part of fixed-base structure to help resisting gravity load. As seismic alternative, isolation of suspended part was opted so that the isolated-suspended part can move over the fixed-base structure during the earthquake.

Figure 3 illustrates the plan geometry for seven-story EDMMC. All spans have the length of 5 meter in x direction and 6 meter in y direction.

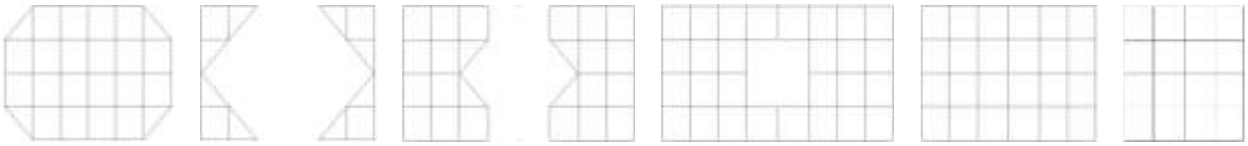

Figure 3: plan geometry for seven-story EDMMC; from left to right: underground 2, 1 and ground floor, mechanical floor, second floor, third floor, fourth floor, roof

For the seven-story EDMMC, the main concept for architectural design has been inspired by innovative seismic concepts including isolation and suspension which point out the principles of discontinuity and motion for new seismic design [5]. The proposed method and concepts has the great potential of making attraction and creativity inside and thus innovative complex form can be seismically safe generated even more safer than regular and traditional ones using the proposed seismic design procedure.

Functions

According to the required functions and space needed for each function and considering the ability of quickly changing function into another predetermined function, the following functions are deemed to create within the complex (Sum of total areas: 4440 m^2).

Floor -2: firefighting and other saving machines and instruments (total area: 660 m^2)

Floor -1: public parking (total area: 660 m^2)

Ground floor: theater, conference and meeting hall → temporary occupation (total area: 660 m^2)

Floor 1: mechanical floor, used for all mechanical and electrical equipment needed in disaster times (total area: 240 m^2)

Floor 2: (total area: 660 m^2)

- Right side: technical exhibition of earthquake and its achievements (sloped area could be used for this purpose), drug store → emergency hospital
- Left side: cultural exhibition of Iran and Iranian, drug store → emergency hospital

Floor 3: (total area: 840 m^2)

- Right side: educational classes (sloped areas could be used for this purpose), shopping stores with in and outside access → psychological consultancy
- Left side: food stores (all restaurant, café, etc. should supply their basic foods, materials and ingredients), casual restaurant and cafe with in and outside access
- Balconies: exterior access of shopping stores, restaurant, cafe and places for seat

Floor 4: (total area: 720 m^2)

- Right side: information and communication technology (ICT), management office and places for disaster management meetings
- Left side: formal restaurant and café for special guests

Roof: roof garden (total area: 480 m^2)

6. STRUCTURAL MODELING

The structure of the proposed EDMMC has inherent complexity within its configuration. The SAP2000 version 14 was opted for structural and seismic analysis. At first, the main concern was the performance of the system against gravity loads. Preliminary design for the structure was done considering gravity and seismic loads and preliminary sections resulted.

Three lines of column located besides and at the top of the fixed-base part of the structure should have been isolated and thus isolator link element was modelled at the base of these fifteen columns. The type of isolators was decided to be Lead Rubber Bearing (LRB) to benefit from energy dissipation, low yield shear strength, high initial shear stiffness and good fatigue features of lead core. (This is demonstrated during the nonlinear seismic analysis that for the isolation system which consists of different heights of isolation level to work with best performance upper line isolators should act like rollers). Links parameters were calculated [6] and [8]. Calculation results can be seen in table 3.

Table 1: link properties definitions

Link	DOF	Trans KE Kgf/m	Trans CE Kgf-s/m	Trans K Kgf/m	Trans Yield Kgf	Ratio
LRB	U1	2.485E+10	0.00			
LRB	U2	25771000.00	471000.00	370000.00	464700.00	0.2
LRB	U3	25771000.00	471000.00	370000.00	464700.00	0.2
ROLLER	U1	2.485E+10	0.00			
ROLLER	U2	384000.00	471000.00	5000.00	223800.00	0.2
ROLLER	U3	384000.00	471000.00	5000.00	223800.00	0.2

7. SEISMIC ANALYSIS

The structure of the proposed EDMMC should be operational after even a severe earthquake. This means that the objective of nonlinear analysis should be set to remaining in Immediate Occupancy performance level. Since the proposed EDMMC is deemed to be constructible in each 22 district of the city of Tehran, different ground motion records were selected to cover various ranges of PGA from 0.04g to 0.97g and different frequency content for both near and far field earthquake (table 2), [10].

Table 2: Ground motion records characteristics; left: far-field EQs, right: near-field EQs

Record-station	PGA (g) (X,Y,Z)	Distance to fault rupture (km)	Significant duration (s) (X,Y,Z)	Magnitude (M)
CHICHI-CHY022	0.065 0.044	71.64	35.876 39.952	7.6
CHICHI-TCU045	0.474 0.512	24.06	11.275 10.815	7.6
KOBE-KAKOGAWA	0.251 0.345	26.4	13.15 12.86	6.9
LOMAP-COYOTE LAKE DAM	0.151 0.484	21.8	15.7 12.22	6.9
NORTHRIDGE-OBREGON PARK	0.563 0.355	37.9	10.92 11.32	6.7
SANFERNANDO-128 LAKE HUGHES	0.366 0.283	20.3	10.73 11.89	6.6
TABAS-79 BOSHROOYEH	0.107 0.089	26.1	19.56 19.14	7.4
VICTORIA-CERRO PRIETO	0.621 0.587	34.8	8.57 7.56	6.4
WHITTIER NARROWS-COLDWATER CAN	0.118 0.25	30.6	11.08 10.18	6

Record-station	PGA (g) (X,Y,Z)	Distance to fault rupture (km)	Significant duration (s) (X,Y,Z)	Magnitude (M)
CHICHI-CHY080	0.968 0.902 0.724	6.95	21.76 21.9 6.17	7.6
DUZCE-LAMONT 1058	0.111 0.073 0.07	0.9	13.13 14.16 14.39	7.1
FRIULI-8014 FORGARIA CORNINO	0.26 0.212 0.095	13.5	4.48 4.52 6.47	6.1
LOMAP-SARATOGA	0.512 0.324 0.389	13	9.36 8.29 9.575	6.9
SUPERSTITN HILLS-286 SUPERSTITION	0.682 0.894	4.3	12.28 12.24	6.7

Nonlinear time history analysis is performed for all fourteen earthquakes to evaluate and then retrofitting of the structure.

Table 3 shows the maximum story drift ratios of the structure in most critical story (the first story of isolated part with 6m columns)

Table 3: maximum story drift ratios

earthquake	max-drift-X	max-drift-Y
F-CHY022-S	0.007	0.004
F-CHITCU045-S	0.0072	0.0062
F-KOBEKAK-S	0.0063	0.0061
F-LOMAPCYC-S	0.0073	0.0072
F-NORTHRODBR-S	0.0027	0.002
F-SFERNL-S	0.002	0.0016
F-TABASBOS-S	0.01	0.0053
F-VICTCPE-S	0.0064	0.0056
F-WHITTIERACWC	0.0012	0.0017
N-CHICHICHY080-S	0.009	0.008
N-DUZCE-S	0.007	0.0055
N-FRIULIB-FOC-S	0.0013	0.0028
N-LOMA-PSTG-S	0.0065	0.0087
N-SUPERSTB-SUP-S	0.0081	0.0075

As it can be seen in table 3, the maximum drift ratio belongs to the CHICHI earthquakes with near fault station and acceleration of 0.97g. After nonlinear analysis under this earthquake, the structure showed hinges formation in “IO” level and ensure that structure remains operational after this special earthquake.

Conceptual and conventional configuration comparison

As it was previously explained the configuration of the complex has been generated based on new seismic principles of discontinuity and movability for passive and hybrid-protected structure to support the architectural needs. To examine the appropriateness of the proposed structure, a traditional structure for the EDMMC with the same configuration but without using the suspension and isolation is also modeled and analyzed and results compared (figure 3).

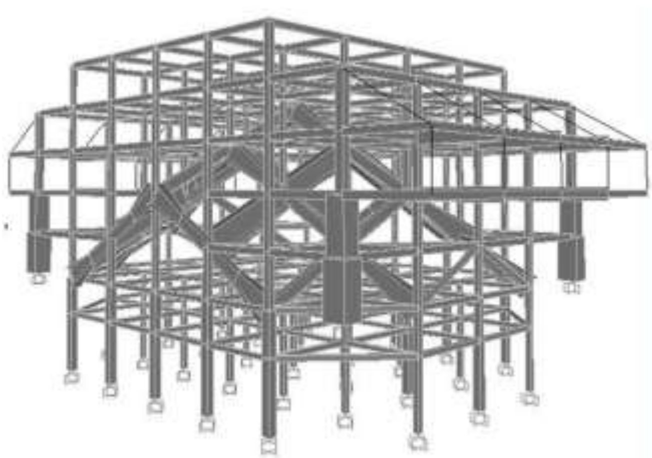

Figure 3: traditional structure without suspension and isolation system

Results comparison

The results are summarized, those critical and those demonstrating the efficiency of the proposed structure are explained.

Figure 4 shows Maximum story shears comparison for the most critical earthquakes of far and near fault.

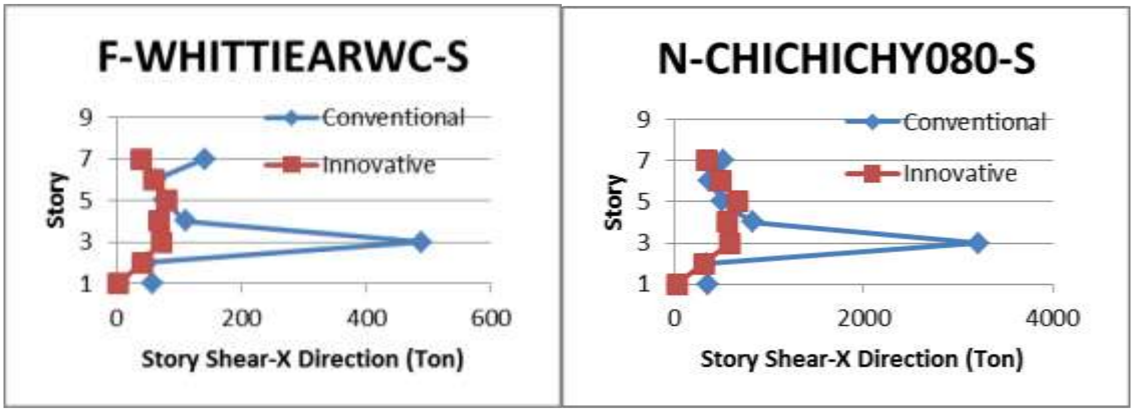

Figure 4: Maximum story shear in X direction

Major decrease is happened in first, third and last floor. This phenomenon is the consequence of three reasons:

- Modal participating mass ratio for conventional structure reaches to acceptable value in mode 5 and 4 for X and Y direction and that makes the behavior of the structure complicated.
- In conventional structure almost all plastic hinges are formed in last story (in B and IO level). Consequently, major flexibility of the structure is supplied by last story resulting in higher shear force.
- Innovative seismic concept employed in the proposed structure resulted in good response.

Figure 5 shows 50% drop for base reactions in some cases when measured for proposed conceptual structure.

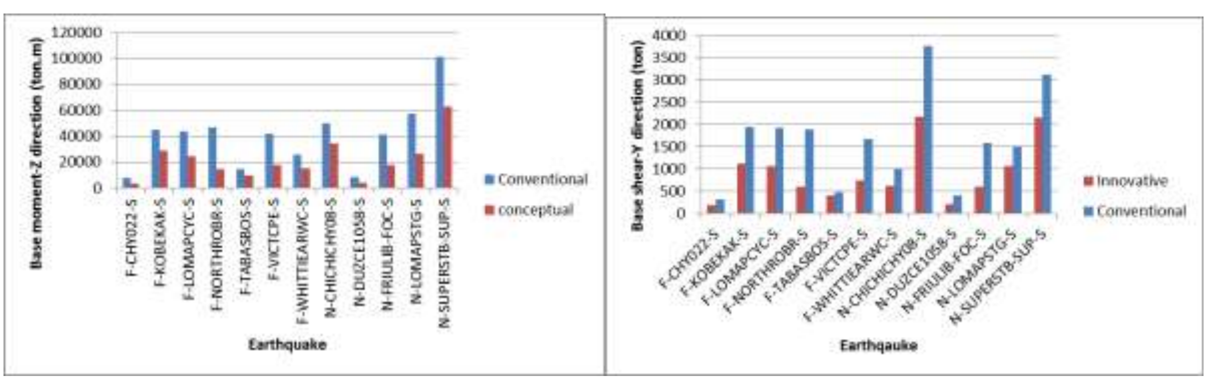

Figure 5: base reactions (base moment in Z direction and base shear in Y direction)

Figure 6 shows the floor acceleration comparison for the most critical earthquakes of far and near fault.

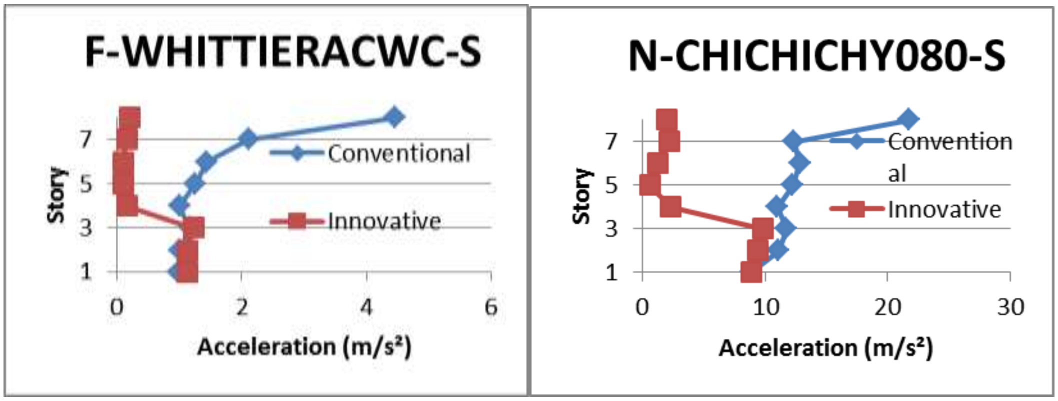

Figure 5: Maximum story acceleration in X direction

The suspended part of the conceptual structure which has been isolated benefits from low acceleration but the value start increasing from the isolation level toward the base of fixed-base structure. The values of acceleration in conceptual structure for all fourteen earthquakes clearly show overall great decrease. High values of acceleration resulted in conventional structure are due to extremely heavy and stiff elements required to remain in "IO" seismic performance level.

The sections resulted after designing both structure to remain operational after earthquake are resulted as bellow (table 4).

Table 4: final section properties; left: conventional structure, right: conceptual structure

Section Name	Material	Shape	t3 (m)	t2 (m)	tf (m)	tw (m)
1000x300	STEEL	I/Wide Flange	1	0.3	0.03	0.03
1500X800	STEEL	I/Wide Flange	1.5	0.8	0.03	0.03
C130x130x5	STEEL	Box/Tube	1.3	1.3	0.05	0.05
C110x110x4	STEEL	Box/Tube	1.1	1.1	0.04	0.04
C30X30X0.5	STEEL	Box/Tube	0.3	0.3	0.005	0.005
C30X30X2	STEEL	Box/Tube	0.3	0.3	0.02	0.02
C35X35X2	STEEL	Box/Tube	0.35	0.35	0.02	0.02
C40X40X2	STEEL	Box/Tube	0.4	0.4	0.02	0.02
C70x70x3	STEEL	Box/Tube	0.7	0.7	0.03	0.03
IPE330	STEEL	I/Wide Flange	0.33	0.16	0.0115	0.0075
IPE360	STEEL	I/Wide Flange	0.36	0.17	0.0127	0.008
IPE400	STEEL	I/Wide Flange	0.4	0.18	0.0135	0.0086
IPE500	STEEL	I/Wide Flange	0.5	0.2	0.016	0.0102
IPE600	STEEL	I/Wide Flange	0.6	0.220000	0.019	0.012
IPE750X222	STEEL	I/Wide Flange	0.778	0.266	0.0296	0.017

Section Name	Material	Shape	t3 (m)	t2 (m)	tf (m)	tw (m)
800X300	STEEL	I/Wide Flange	0.8	0.3	0.03	0.03
C35X35X2	STEEL	Box/Tube	0.35	0.35	0.02	0.02
C40X40X2	STEEL	Box/Tube	0.4	0.4	0.02	0.02
IPE300	STEEL	I/Wide Flange	0.3	0.15	0.0107	0.0071
IPE330	STEEL	I/Wide Flange	0.33	0.16	0.0115	0.0075
IPE360	STEEL	I/Wide Flange	0.36	0.17	0.0127	0.008
IPE400	STEEL	I/Wide Flange	0.4	0.18	0.0135	0.0086
IPE500	STEEL	I/Wide Flange	0.5	0.2	0.016	0.0102

Extremely heavy sections resulted in conventional structure which is impractical and just used as comparison.

8. CONCLUSION

Since creating earthquake disaster management multi-purpose complexes have been demonstrated to be necessary in large seismically prone cities, in this paper the process of architectural and structural design of a proposed scheme for the city of Tehran based on new seismic concepts explained. The proposed structure overcame the problem of adding four stories safely above a large free-of-column space by using the concept of suspension and isolation. The conceptual proposed structure was demonstrated by nonlinear time history analysis to have good performance and remains operational after the earthquake. For the comparison, a conventional structure with the same configuration but without suspension and isolation designed in "IO" performance level and results compared to the conceptual proposed structure. The research opens up new visions in architectural design of buildings equipped with passive or hybrid protection system since the performance of these devices greatly depends to the architectural configuration.

9. REFRENCES

1. Hosseini. M, "Creating multi-purpose complexes with special architectural and structural design for community-based disaster risk management in large cities", first national conference on architecture and structure, university of Tehran. Iran, 2006
2. Hosseini. M, "Seismic considerations in architectural design of special buildings", proceeding of 6th international conference on civil engineering, Isfahan, Iran, 2003
3. Parducci, A. Seismic Isolation and Architectural Configuration, Special Conference on the Conceptual Design of Structures, Singapore, 2001
4. Seyedinnoor. S.P and Hosseini. M, "Architectural Forms for Enhancing the Seismic Safety of Buildings Equipped with Innovative Seismic Protection Systems", international conference of architecture and structure, university of Tehran, Iran, 2011
5. Mezzi, M. Configuration and morphology for the application of new seismic protection systems. 1st European Conference on Earthquake Engineering and Seismology. Geneva, Switzerland, 2006.
6. Naeim, F., Kelly J. M. (1999), Design of Seismic Isolated Structures. John Wiley & Sons. New York, 1999.
7. Federal Emergency Management Agency, (FEMA), 2000: Prestandard and Commentary for the Seismic Rehabilitation of Buildings, number 356.
8. Uniform building code, 1997, (UBC 97); division 4, earthquake regulations for seismic isolated structures.
9. SAP2000, user manual (cable modeling), CSI, Inc., Berkeley, California, 2009.
10. http://peer.berkeley.edu/nga/search.html