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Seismic Behavior of IUM Conference Building under the Impact of Seismic Loads

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Abstract: For the buildings of importance, it is essential to focus attention on knowing the behavior of these buildings towards resisting wind loads and seismic loads and finding the stresses resulting from this resistance to make a reliable design that guarantees the safety of these buildings. In this paper, a "conference building" located at Islamic University in Madinah region has been studied under the impact of seismic load. It has been analyzed to ensure its ability to resist seismic load stably. Al-Madinah region is located between two seismic zones (0 and 1) as stated in the Saudi Arabia zonation map which has factors of 0.05g and 0.075g respectively. According to that, the structure was checked for a higher seismic zone (zone 2A) of a Peak Ground-Acceleration (PGA) of 0.15g and this was done according to Eurocode-8 (EC8) requirements and the analysis was carried out manually and by using SAP2000. According to the results obtained using the shear wall system, the building had exhibited very high stability against seismic load by more than three times against sliding and 24 times against overturning. The building's elements were designed and the selected sections have been found suitable for exerting good performance.

Keywords: Seismic Loads, Response Spectrum, Base Shear, Building Stability.

1. Introduction

Buildings designed and constructed integrating seismic behavior, perform remarkably well, whereas precast concrete structures perform seismic behavior that was not designed and detailed as requirements of standards. These exhibits poor during past earthquakes [1]. Precast concrete structures are being used widely in the world for the excellent performance in resisting earthquakes.

The use of precast concrete in construction has many advantages, such as high-quality control, speediness in construction time, more durability, reduction in formwork cost of labor, and leads to social and environmental gains. Due to the miss consideration of the basic nature of seismic behavior, the precast concrete structures were regarded with doubt in seismic zones [2].

Using of precast concrete in Some countries showed bad performance in significant earthquakes. Cases of poor performance of precast concrete building structures are well documented after Tangshan (China-1976), Michoacan (Mexico-1985), Armenian (1988), Northridge (1994), and Kocaeli (1999) earthquakes. This might be due to incorrect design and detailing of the ductile element, bad diaphragm performance, poor connection and joint details, lack of separation of non-structural elements, and unstable separation between structures. (FIB, 2003 another example is the damage to precast school buildings in Gujarat in the 2001 Bhuj earthquake due to the bad connections between structural elements. Ref. [3] reported that the roof shelf resting on the beam shifted due to the insufficient bearing area and bad positive anchorage. A monolithic behavior of frames and diaphragms action of floors could not be gained due to bad connections.

Recently, and to reduce damage in structures, precast elements were used by focusing on developing techniques of experimental investigations. For example, the University of Canterbury in New Zealand showed tests to design connection details between hollow-core floors with beams and walls [4, 5, 6] that could withstand up to 6% of inter story drift. Also, innovative techniques such as 'damage avoidance design (DAD)' and 'self-centering technique' are used in post-tensioning systems. They developed rocking walls and columns that performed with no damage even up to a 4.7% drift level. The precast concrete structures have shown good performance under seismic conditions from the above discussion.

Hassaballa et al [7] studied the design of reinforced concrete columns of a hospital building in Sudan considering wind loads and seismic loads following the provision of Egyptian Society for Earthquake Engineering (ESEE). They used equivalent static method performed using the SAP2000, and the analysis resulted in an unsafe structure compared with the former design based on lateral loads only.

Hassaballa et al [8], review the seismic happenings in the Jazan area together according to the Saudi Building Code (SBC-301-2007) and a multi-story reinforced concrete building in the Jazan city was modeled and analyzed using the Equivalent Lateral Force Procedure using STAAD-PRO Software. The study is highly recommended taking the Saudi seismic code provisions to analyse and design multi-story buildings in the Jazan regions.

2. Seismic Load Pattern Selection

Realistic and natural recordings are the most suitable of all the possibilities to define the structure's seismic inputs for the intent of structural analysis. Attainable waveform databases are obtainable as a piece of the guide showing that only a relatively limited number of principles must be considered in the scaling and selection to get a fair approximation of the seismic request. Eurocode 8 (EC8) permits the use of real ground motion records for the seismic assessment of the structures. The EC8 supports the usage of spectrum-matching records, gained by emulation of real records [9]. According to ACI318-14 Code, the load combinations were implemented as described below.

U = 1.4D

U = 1.2 D + 1.6L

U = 1.2D + 1.0E + 1.0L

U = 0.9D + 1.0E

2.1. Peak Ground Acceleration (PGA):

PGA is equal to the maximum ground acceleration that happens throughout the earthquake at a location and is similar to the amplitude of the most enormous absolute acceleration recorded on an accelerogram at a site during a particular earthquake [10].

2.2. Seismic Zonation and Seismic Factors:

The Madina region is located between two seismic zones as shown in Fig. (1) below (highlighted by red dot). Seismic zone 0 has a factor of 0.05g whereas 1 has a factor of

0.075g. This research suspects the structure for a higher seismic zone 2A of a factor 0.15g as shown in Table (1) [11]. The response spectrum for a site in Zone 1 and Zone 2A for the probability of exceedance of 10% is shown in Figures (2) and (3) as referenced by M.S.Al-Haddad and G.H.Siddiqi [11].

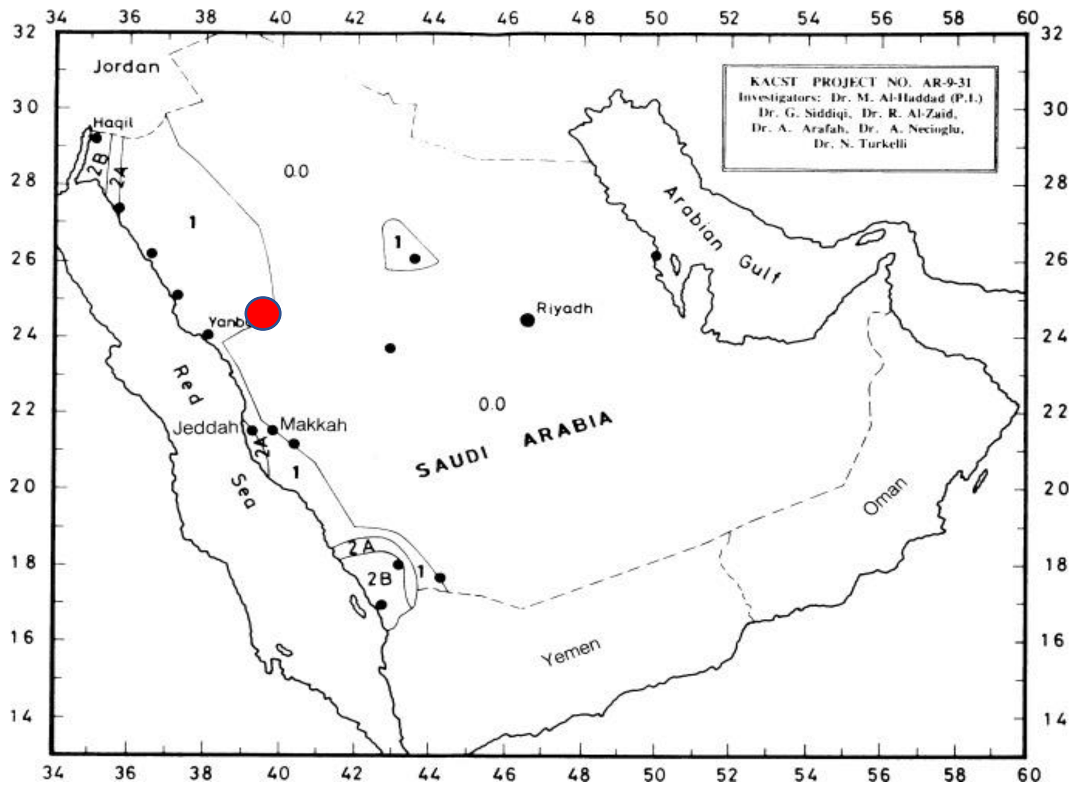

Fig. (1). Saudi Arabia zonation map

Table (1). Seismic Factors of Seismic Zone Number (SZN).

SZN	**0**	**1**	**2A**	**2B**
Factor	0.05	0.075	0.15	0.2

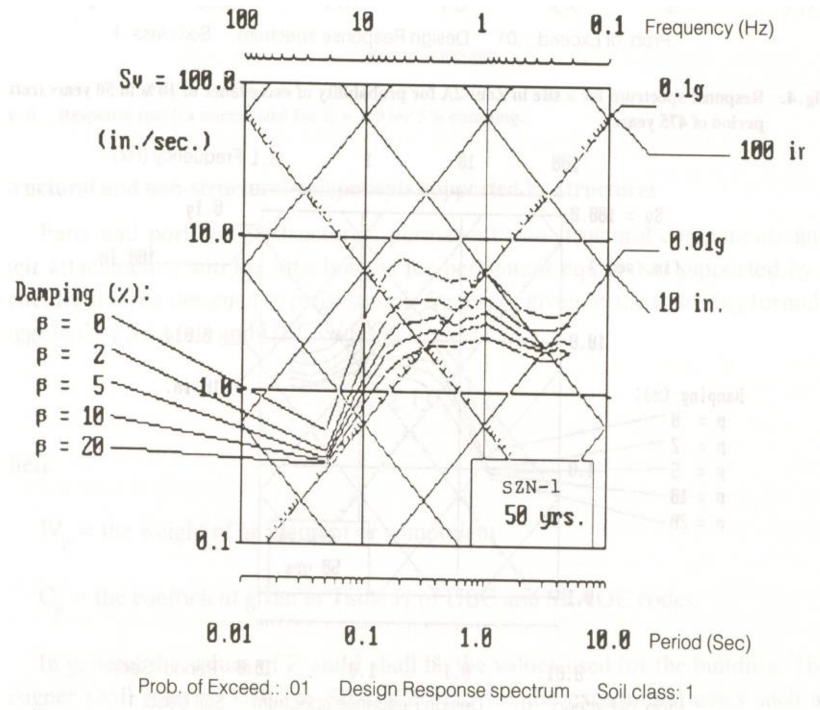

Fig. (2). Site in Zone 1 Response Spectrum for Exceedance Probability of 10% in 50-Years (Return-Period of 475-Years).

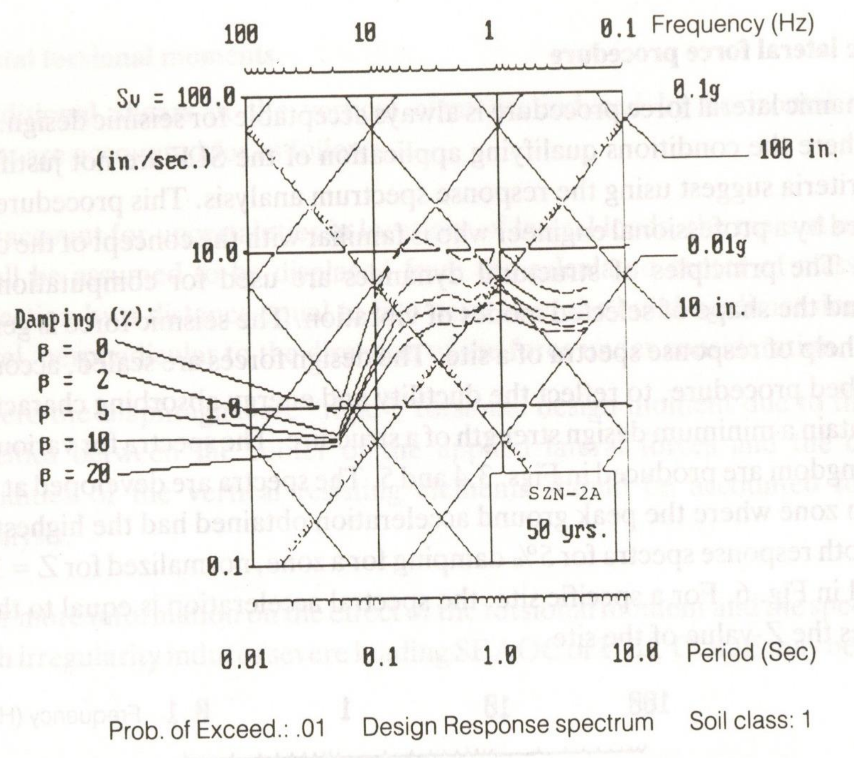

Fig. (3). Site in Zone 2A Response Spectrum for Exceedance Probability of 10% in 50-Years (Return-Period of 475-Years).

3. The Studied Building

This building is significantly important to the Islamic University as it is considered the largest facility on the university campus. Highlight the fact that the presence of many activities makes it a symbol of the Islamic University. The construction of the Islamic University conference hall started in 2012. The project is supposed to have meeting conferences, graduation ceremonies, and other various activities including a media hall within the project. Structurally, the conference hall is composed of a basement, ground floor, first roof, and roof floor. The building height above the base is 24.569 m and has a circular shape with a radius of 53m. Shear walls were used to improve the stiffness and hence to increase the effectiveness of the building to resist lateral loads and located symmetrically for more stability as shown in Fig. (6). [12,13].

The structural components of the conference building are various, each part of the building has a different type of slabs consists mostly of precast Double-T slabs, Hollow core slabs, solid slabs, and flat slabs, beam with six main types, these are Doubly reinforced beams, dropped beams, inverted T-beams, L-beams, inverted L-drop beams and curved beams. Columns are arranged in large distances for architectural purposes with using different sections and the structural members will be checked and redesigned with different loadings such as live loads which was selected according to ASCE with different values of 2.87 kN/m^2 for the theaters (arenas with fixed seats), 4.79 kN/m^2 for lobbies, 2.4 kN/m^2 for offices, 0.96 for roofs without occupancy. the dead loads were calculated according to the densities of materials used.

This paper aims to obtain the results of building sustainability against seismic load and how it would behave at distinct locations of height seismicity zones.

4. Design Spectrum for Elastic Analysis

Regarding Fig. (4) shown below, and according to clause 3.2.2.5 in EN-1998-1-2004-(E), the following expressions define the horizontal-components of the seismic-action and the elastic response-spectrum $S_d(T)$ [see Equations (1) to (4)].

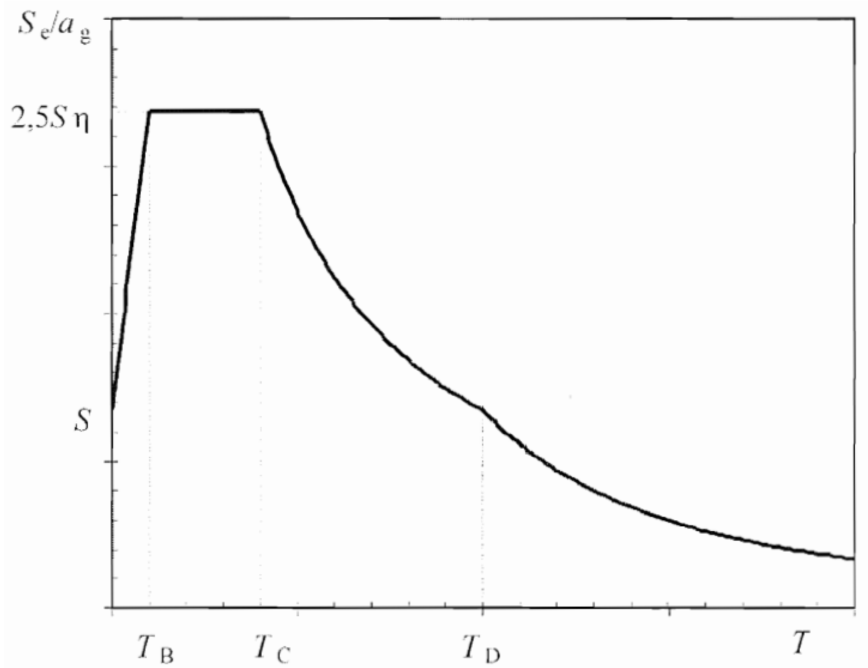

Fig. (4). Shape of Elastic Response Spectrum.

$$0 \leq T \leq T_B: \quad S_d(T) = a_g\, S \left[\frac{2}{3} + \frac{T}{T_B}\left(\frac{2.5}{q} - \frac{2}{3}\right)\right] \tag{1}$$

$$T_B \leq T \leq T_C: \quad S_d(T) = a_g\, S\, \frac{2.5}{q} \tag{2}$$

$$T_C \leq T \leq T_D: \quad S_d(T) = \begin{cases} a_g S\, \dfrac{2.5}{q}\left[\dfrac{T_C}{T}\right] \\ \geq \beta\, a_g \end{cases} \tag{3}$$

$$T_D \leq T: \quad S_d(T) = \begin{cases} a_g S\, \dfrac{2.5}{q}\left[\dfrac{T_C T_D}{T^2}\right] \\ \geq \beta\, a_g \end{cases} \tag{4}$$

Where:

$S_d(T)$ is known as the design-spectrum.

T is considered for a linear single-degree-of-freedom system as the vibration-period.

a_g is considered for type-A ground as the design ground-acceleration.

T_B is obtained from the constant spectral-acceleration as the lower-limit of its period.

T_C is obtained from the constant spectral-acceleration as the upper-limit of its period.

T_D is the beginning value of the constant displacement-response range of the spectrum.

S is defines as the soil-factor.

Q is defines as the behavior- factor.

β is defined as the lower-bound factor obtained from the horizontal design-spectrum.

4.1. Failure Analysis:

It presents the lateral seismic loads according to Eurocode-8 2004, following the total load calculated, which was found as 10901-Tone [14,15].

4.2. Spectrum Type:

These are Type-1 spectra (for regions with high seismic activity and long-period ground motions) or Type-2 spectra (for regions with low-to-moderate seismic activity and short-period ground motions).

4.3. Factors and Coefficients:

According to Table 3.1 of EN 1998-1:2004 (E) [16], the ground type is (B), which means either very stiff clay or gravel or very dense sand. The parameters values of the elastic response-spectra considered for Type 1 are outlined in Table (2). For all diaphragms, direction and eccentricity ratio is regarded as 5%. According to EC (4.3.3.2.2), and for moment resistant space concrete frames, the coefficient, C_t is taken 0.075.

Table (2). Parameters Values.

a_g	S	T_B (Sec)	T_C (Sec)	T_D (Sec)	β_0	q
0.15g	1.2	0.15	0.5	2	0.2	4

4.4. Structural analysis using SAP2000:

The structural analysis of the IUM conference hall was mainly depending on the behavior of the building under seismic loading. Both static and dynamic loads were applied to the structure. The detentions of the materials, diaphragms, property modifiers, and mass source is given as the following:

1. Concrete cylinder compressive strength: C35
2. Diaphragm type (joint) for calculating centers of mass and rigidity: rigid
3. Diaphragm type (joint) for dynamic analysis: semi-rigid
4. Mass source: specified load patterns with live load reduced to 0.25

The framing type for satisfying the minimum flexural strength of columns considering beam to column connection was considered as sway ordinary.

4.5. Base Shear Calculation:

The base shear can be calculated according to EC8 Equation (4.5):

$$\boldsymbol{F_b = S_d(T_1)\, m\, \lambda} \quad (5)$$

Where:

S_d is the design-spectrum ordinate at period (T_1).

T_1 is fundamental-period.

m is the total mass of the building.

λ is the correction factor.

Estimate fundamental natural period (T_1) according to EC8 Equation 4.6:

$T_1 = C_t H^{0.75}$

$T_1 = 0.075(24.569)^{0.75} = 0.828s$

For $T_C \leq T \leq T_D$ *, use Eqn. (3)*

$S_d(T_1) = a_g S\ \dfrac{2.5}{q}\left[\dfrac{T_C}{T_1}\right]$

$S_d(T_1) = 0.15(9.81)(1.2)\left(\frac{2.5}{4}\right)\left[\frac{0.5}{0.828}\right] = 0.67\ m/s^2$

Where: $T_1 < 2T_C$, so $\lambda = 0.85$.

$F_b = 0.67(10901)(0.85) = 6208$ kN

The corresponding building weight = 10901(9.81) = 106,938.8 kN

Net horizontal force is: $\frac{100(6208)}{106{,}938.8} = 5.8\%$ of total weight.

4.6. Distribution of the Horizontal Seismic Forces:

Horizontal force (F_i) is given by Equation (6) in accordance to Equation (4.11) of EC-8.

$$\boldsymbol{F_i = F_b \frac{z_i m_i}{\sum z_j m_j}} \quad (6)$$

Where: z_i, z_j are the height of masses m_i , m_j.

4.7. Shear Forces and Bending Moments:

The shear force (Q_i) and bending moment (M_i) for each story level are being calculated by using F_i by starting calculation from the upper level ($Q_{upper} = F_{upper}$; $M_i = Q_{upper}(h_{upper} - h_{upper-1})$ and the subsequent other levels are calculated according to Equations (7) and (8).

$$\boldsymbol{Q_i = Q_{i-1} + F_i} \quad (\mathbf{7})$$

$$\boldsymbol{M_i = M_{i-1} + (Q_i h_i)} \quad (\mathbf{8})$$

Where: $h_i = H_i - H_{i-1}$

Table (3). Calculation of Forces for each Level of Building.

Story	**Elevation (H), (m)**	**Weight, (kN)**	**F_i, (kN)**	**Shear Force (Q_i), (kN)**	**h_i, (m)**	**Moment (M_i), (kN.m)**
Roof C	24.569	32.33	42.7	42.7	2.5	106.66
Roof B	22.069	1166.1	1382.2	1424.9	2.903	4136.43
Roof A	19.166	1548.6	1594.1	3019.0	5.8	17510.36
First Floor B	13.366	2159	1549.9	4569.0	2.3	10508.60
First Floor A	11.066	1111.2	660.5	5229.4	5.2	27192.93
Ground Floor	5.866	3106	978.6	6208.0	5.866	36416.13

5. Check for Sliding and Overturning

The lateral load due to seismic load tends to slide and overturn the building (Fig. (5)), now, checks should be done to ensure the structure is stable against the two actions.

A value of 1.5 factor of safety is used in most codes of practice, considering the partial factor for the load combinations considered. For sliding a value of 0.3 can be taken for the coefficient of friction.

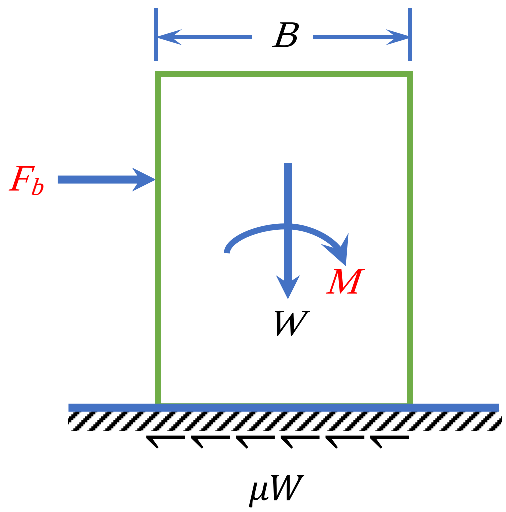

Fig. (5): Building and Forces Parameters that use for checking Stability.

5.1. Check Sliding:

$$\text{Sliding force (working)} = \frac{F_b}{1.4} = \frac{6208}{1.4} = 4{,}434.3\ \text{kN}$$

$$\text{Total working weight of building} = \frac{10901(9.81)}{1.4} = 76{,}385\ \text{kN}$$

$$\text{Resisting force} = 0.3(76{,}385) = 22{,}915.5\ \text{kN}$$

$$\text{Factor of Safety} = \frac{\text{Resisting force}}{\text{Sliding force}} = \frac{22{,}915.5}{4{,}434.3} = 5.2 > 1.5\ \rightarrow \text{Safe}$$

5.2. Check Overturning:

$$\text{Overturning Moment(working)} = \frac{M_{base}}{1.4} = \frac{36416.1}{1.4} = 26{,}011.5\ \text{kN.m}$$

$$\text{Resisting Moment} = 76{,}385\left(\frac{B}{2}\right) = 76{,}385\left(\frac{25}{2}\right) = 95{,}4812.5\ \text{kN.m}$$

$$\text{Factor of Safety} = \frac{\text{Resisting Moment}}{\text{Overturning Moment}} = \frac{95{,}4812.5}{26{,}011.5} = 36.7 > 1.5\ \rightarrow \text{Safe}$$

6. Response Spectrum

By using the data listed in Tables (1) and (2), and applying it in SAP2000 software. The program can first start the period of mode calculated to achieve the most prominent factor of participation in that direction in which the loads which will be needed for calculation

(X or Y). Eight modes had been used and one of them was selected which was concurrent with the period of 0.658s. On that, the results of calculations obtained were detailed as shown below:

- The response spectrum calculations are shown in Table (4).
- The base shear concise with the period of 0.658 is 9143.5-kN and was distributed as shown in Table (5) for the two directions.
- The deformed shaped pattern due to seismic load at direction Y is shown in Fig. (6).
- The horizontal displacements through all the stories of the building in the two directions are shown in Table (6) and presented graphically as shown in Fig. (7).
- Sample of output results are illustrated in Figures. (8,9,10).

Table (4). Response Spectrum Calculation.

Time (s)	**Acceleration (m/s^2)**
0	0.12
0.05	0.1175
0.1	0.115
0.15	0.1125
0.5	0.1125
0.75	0.075
1	0.05625
1.25	0.045
1.5	0.0375
1.75	0.032143
2	0.03
3.333	0.03
4.667	0.03
6	0.03
7.333	0.03
8.667	0.03
10	0.03

Table (5). Shear Force Distribution in Directions X and Y Calculated by SAP2000 for the Period of 0.658s.

Story	**Elevation, m**	**Force in X-Dir., kN**	**Force in Y-Dir., kN**
Roof C	24.569	62.7808	66.8483
Roof B	22.069	2033.9321	2165.7094
Roof A	19.166	2345.7643	2497.745

First Floor B	13.366	2280.6964	2428.4614
First Floor A	11.066	975.3091	1038.4988
Ground Floor	5.866	1445.0166	1538.6384
Base	0	0	0

Table (6). Displacements in Directions X and Y Calculated by SAP2000.

Story	Elevation (m)	D_X (m)	D_Y (m)
Roof C	24.569	0.098	0.033
Roof B	22.069	0.094	0.032
Roof A	19.166	0.091	0.03
First Floor B	13.366	0.075	0.026
First Floor A	11.066	0.066	0.023
Ground Floor	5.866	0.042	0.016
Base	0	0	0

As shown in Table (6), the direction Y exhibits more resistance against lateral displacement due to the high resistance provided by the shear wall.

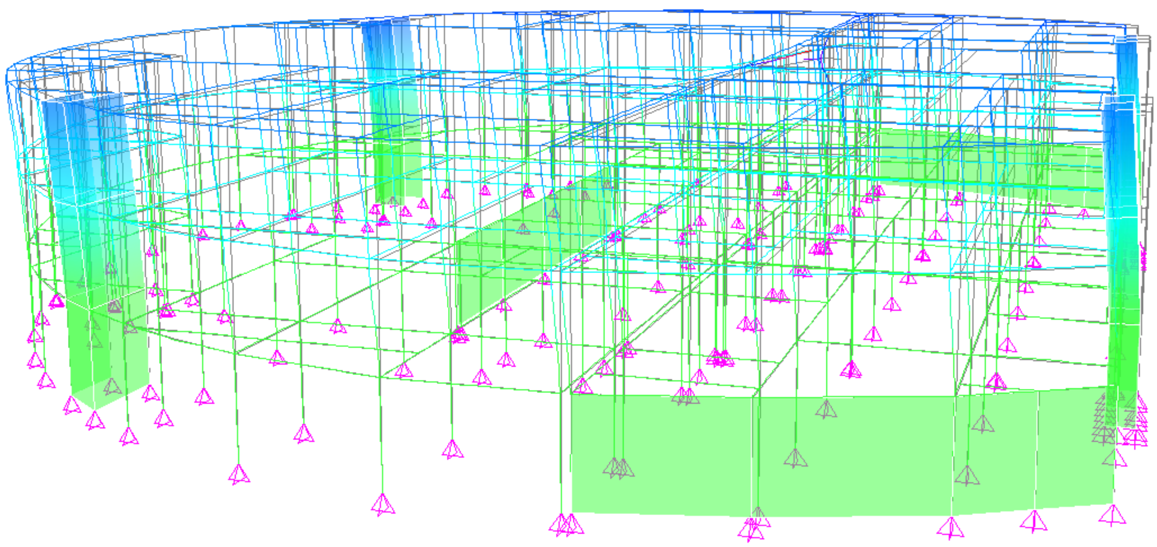

Fig. (6). Building Deformation under action of seismic load at direction Y

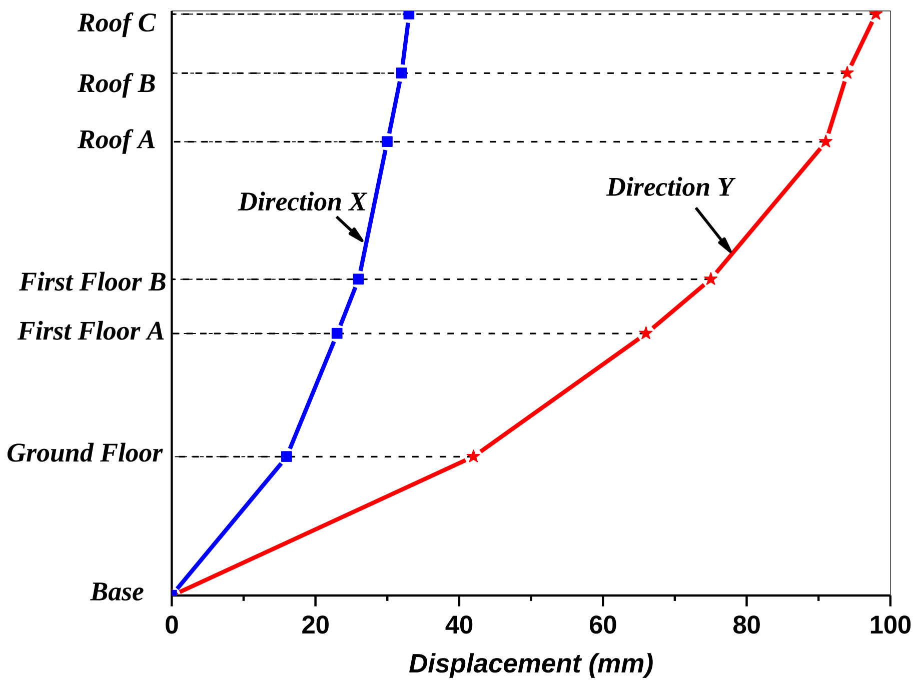

Fig. (7). Horizontal joint displacements along with the height of building due to seismic load at two directions, X and Y

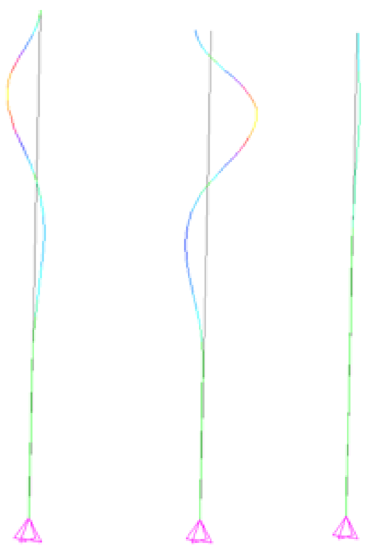

Fig. (8). Sample of modal shapes.

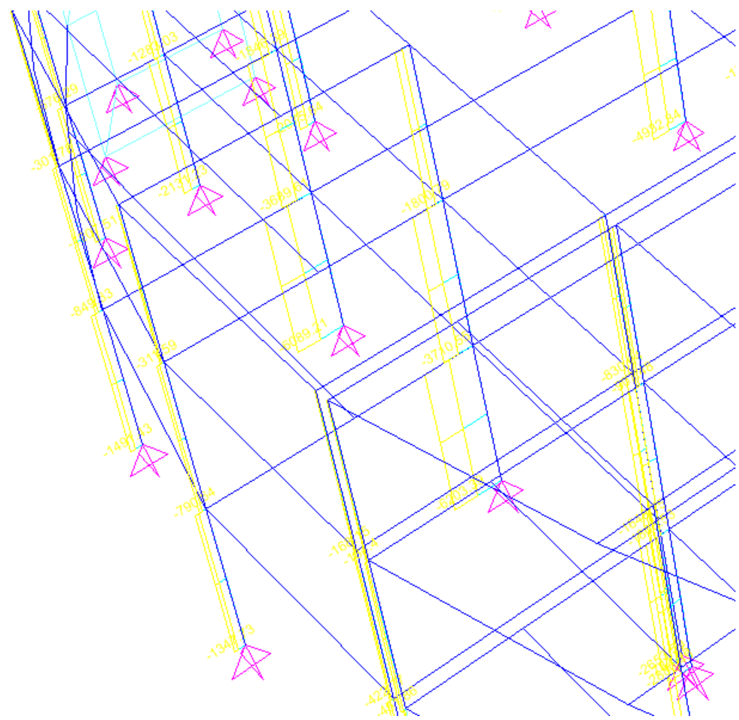

Fig. (9). Axial forces in some columns due to combination of live load, dead load and seismic load.

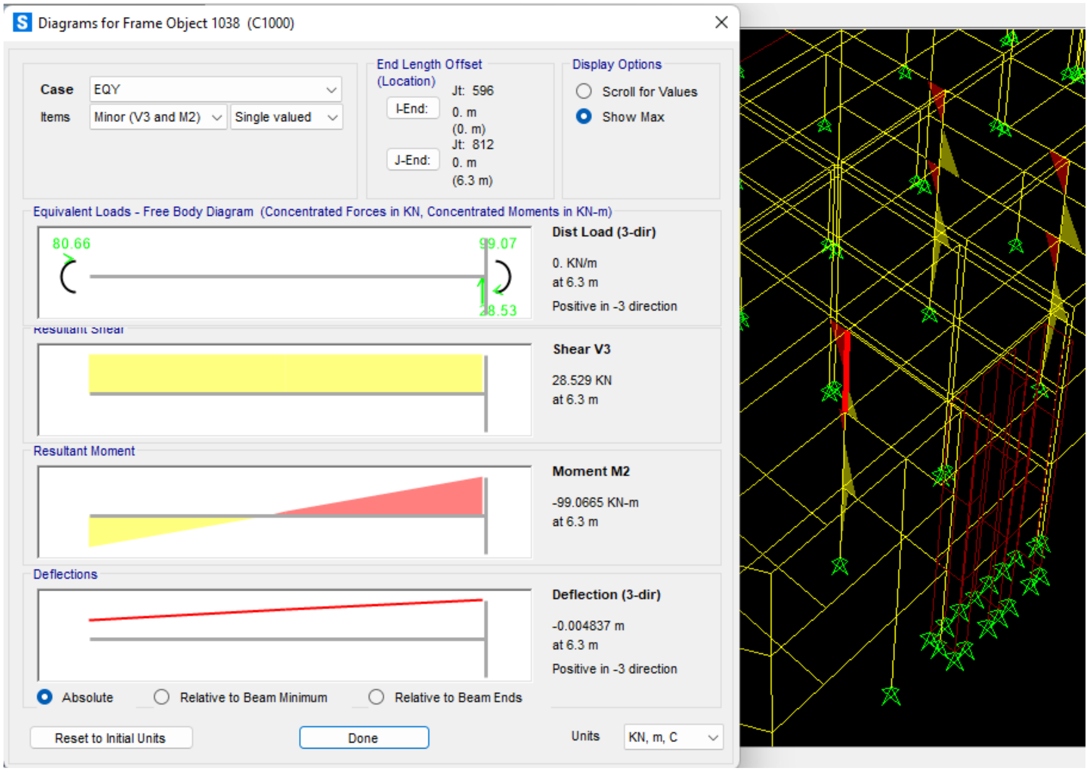

Fig. (10). Shear force and bending moment in the selected column due to seismic load at direction Y.

7. Check and verification of Building Elements

All the building elements were designed according to the requirements of ACI318-14 Code, and the selected elements for beams, columns and shear walls were checked and verified using the SAP programs. The message appears in Figures (11) and (12) ensures that.

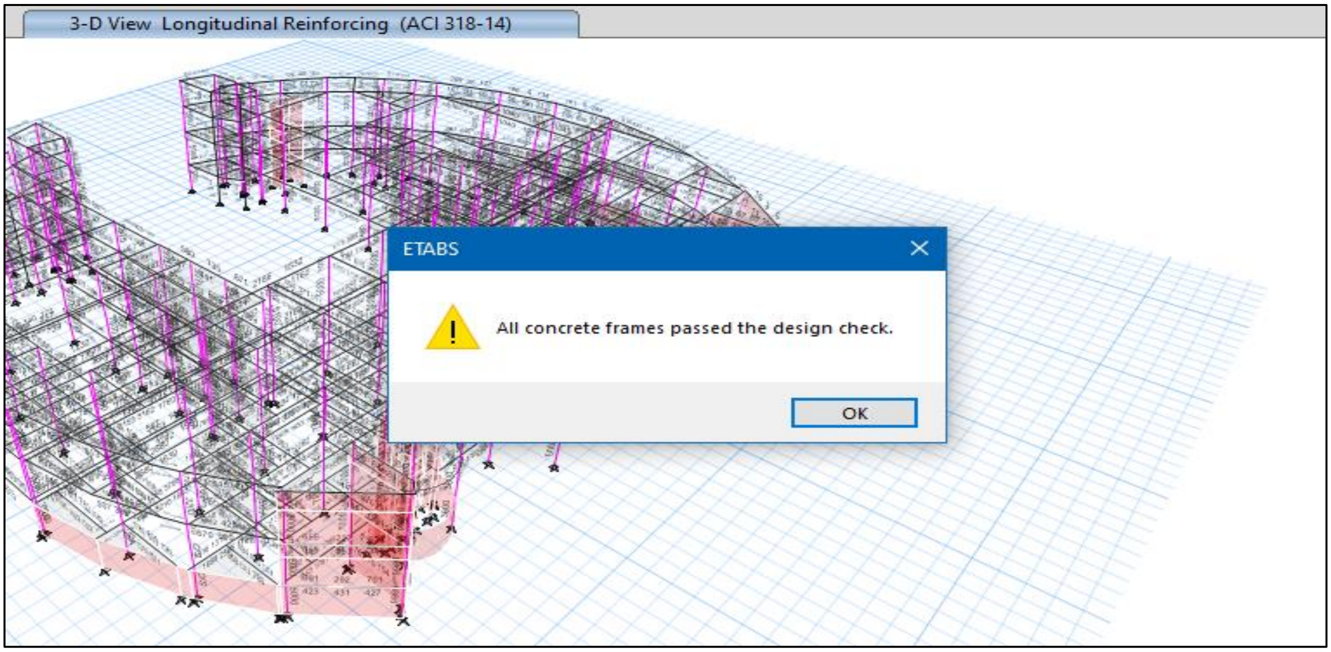

Fig. (11). Design Check for the Beams and Columns of the Building

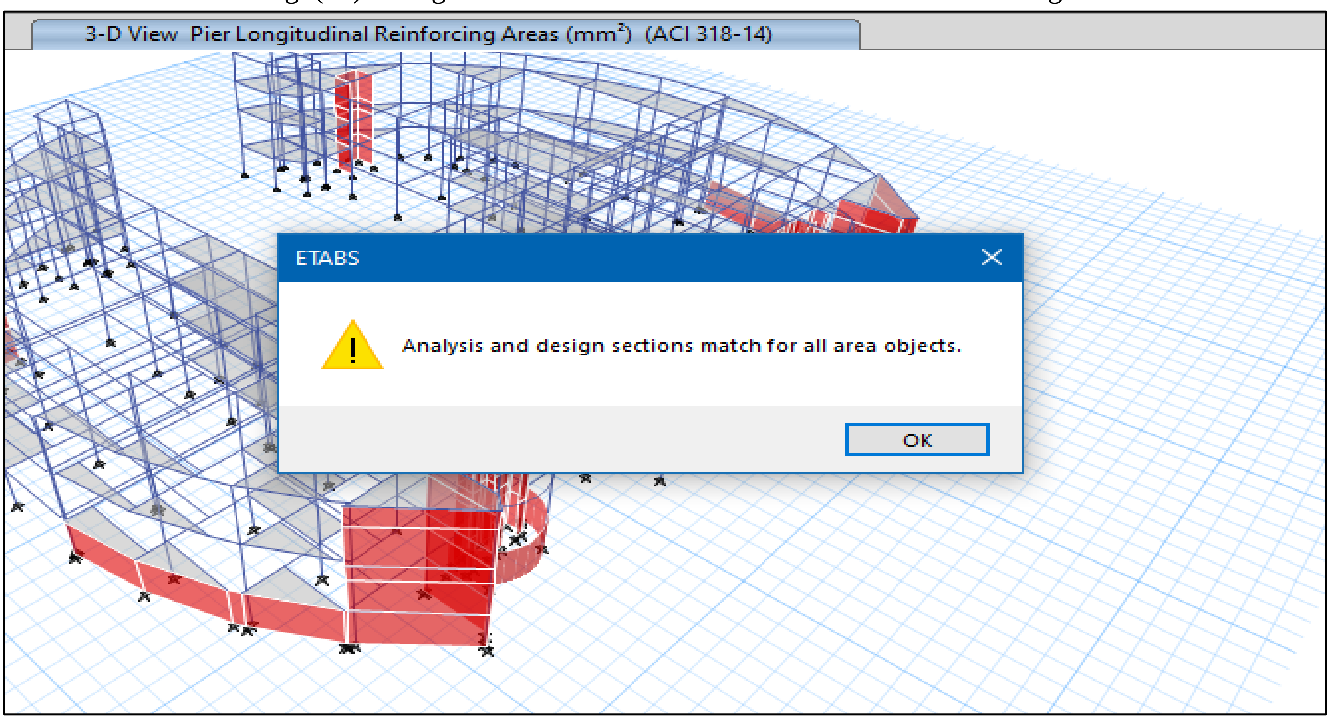

Fig. (12). Check for the element's sections

8. Conclusion

A conference building located at the Islamic University Madinah has been used as a model for this analysis by analysing buildings subjected to the impact of seismic loads. According to the building information and its location concerning the seismic plan, the research was conducted using EC8 both manually and using the SAP 2000 program, and through the results obtained, this paper concluded that:

- From the results obtained by manual analysis, the period obtained is 0.828s, resulting in a base shear of 6208 kN, this led to the net horizontal force of 5.8% of the total weight.
- Building Stability has been checked, and it exhibited high resistance by an amount over the limited value by three times more for sliding and 24 times more for overturning.
- From the results obtained using SAP2000, a suitable modal shape has been selected, giving a period of 0.658s accordingly, the base shear concise is 9143.5kN.
- The building has many shear walls. These walls were included when modeled in SAP2000, so the building exhibited more rigidity, which is the reason for getting a period less in value than that gained by manually calculated.
- The building's elements were designed according to the requirements of ACI-308-14, and all the sections used have been checked and found suitable and matched with the elements.
- It is recommended to include wind loads beside seismic loads to cover all the probable cases.

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Conflict of Interest: Authors declare that is no conflict of interest for publication of this work.

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السلوك الزلزالي لمبنى المؤتمرات الواقع في منطقة المدينة المنورة تحت تأثير الأحمال الزلزالية

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ملخص البحث: بالنسبة للمباني ذات الأهمية، من المهم التركيز على معرفة سلوك هذه المباني تجاه مقاومة أحمال الرياح والأحمال الزلزالية وإيجاد الضغوط الناتجة عن هذه المقاومة لعمل تصميم موثوق يضمن سلامة هذه المباني. في هذا البحث تمت دراسة "مبنى مؤتمرات الجامعة الإسلامية" الواقع في منطقة المدينة المنورة تحت تأثير الحمل الزلزالي وتم تحليله للتأكد من قدرته على مقاومة الحمل الزلزالي بثبات. تقع منطقة المدينة المنورة بين منطقتين زلزاليتين (0 و 1) كما هو مذكور في خريطة المملكة العربية السعودية التي تحتوي على عوامل 0.05 جرام و 0.075 جرام على التوالي وبناءً على ذلك، تم فحص الهيكل لمنطقة زلزالية أعلى (المنطقة 2 أ) لتسريع ذروة الأرض بمقدار 0.15 جم وتم ذلك وفقًا لمتطلبات الكود الأوروبي 8 وتم إجراء التحليل يدويًا وباستخدام ساب 2000. وفقًا للنتائج التي تم الحصول عليها وباستخدام نظام حوائط القص، أظهر المبنى ثباتًا عاليًا جدًا ضد الأحمال الزلزالية تزيد بأكثر من ثلاث مرات لمقاومة الانزلاق وأكثر من 24 مرة لمقاومة الانقلاب. الأعضاء الإنشائية المكونة للمبنى قد تم تصميمها ولقد تم اختيار مقاطع مناسبة لكي تؤدي أداء جيد

كلمات مفتاحية: الأحمال الزلزالية، طيف الاستجابة، قص القاعدة، استقرار المبنى.