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# EVALUATION OF THE ADDED FORCE IN THE SEISMIC DESIGN OF STEEL MOMENT FRAMES IN DIFFERENT SITES OF TEHRAN DUE TO THE INCREASE OF FLOORS

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## ABSTRACT

Moment frames are one of the most widely used structural steel systems, especially for residential use. In the design of such structures, lateral seismic loads and different gravitational loads play a role which according to most design regulations about such structures for the convenience of designers, seismic design spectra and the amount of gravitational loads are determined. Since the forces in the model play an essential role in the design of sections and optimization of materials, especially for high-rise Buildings, in this study using the Site Special design Spectra for 6 different sites in Tehran with Different seismicity and soil types are obtained and using the periodic intervals intended for them, spectral acceleration and final base shear are calculated and according to the loading combinations, the final force is obtained for adding each floor to the model. The results show that the total force of the model increases linearly with the increase of each floor with very high accuracy and the total base shear acts as 2 ascending lines with the increase of the floors, but the force from per added floor for models up to 13 is ascending classes, 4 to 10 descending classes and from 11 to 66 floors is almost constant.

## INTRODUCTION

The first challenge in designing structures is controlling the present forces. The main forces of structural design are due to gravitational loads, both dead and live, and lateral loads, including earthquakes. Dead and live loads of gravity are generally considered in the same way by the regulations, depending on the use of the building. Seismic loads are obtained by different methods and their determine the type of structural analysis. Equivalent and non-linear static analyzes, linear and non-linear dynamic analyzes include spectral types and time-history and incremental are some of the mentioned types of analyzes [1]. Equivalent static analyzes use simple equations to calculate and distribute earthquake base shear that are generally accurate just for regular and short-range frames. To improve the accuracy of seismic analysis, spectral dynamic analysis can be used, which according to the period of the first mode of the structure and the design spectra, including the spectrum of the special design of the site, provides the ability to find spectral acceleration and lateral load distribution. In general, due to the increase in mass and decrease in stiffness in the frame of equivalent single degree of freedom in exchange for the increase of floors, the periodicity of the structure increases [2]. This is while the design spectra in the amplitude of the periodicities under study have mainly descending branches and report less spectral acceleration with increasing periodicity [3]. This raises the question of how the final force and the amount of force decrease or increase with the increase of the number of floors? The answer to this question can help us in the optimal design of structures.

On the other hand, the shape of the design spectrum can be affected by the type of soil and the seismicity of the site. Therefore, the question will be whether the construction site of the models affects the amount of added force per floor?

In this study, with the aim of answering the above questions, the effect of increasing the classes on the amount of moment frame forces will be investigated in a parametric manner. Increasing or decreasing the periodicity of the structure, the shape of the spectrum of the structural designand and so on, which is answered through the use of previous theories and researches as well as the use of Sap and Matlab software in this field [4].

## METHODOLOGY

In general, each structure can be equated with a single-span 3D model on each side. In this research, a three-dimensional model with a single-span moment structural system with 3 meters height in each floor and 3 meters span length, with gravity loads according to Table (1) is considered. Since, according to the regulations, such as Iranian Standard 2800, moment frames with two modes of intermediate and special ductility are proposed, and intermediate moment frames have a permissible height limit of 50 meters, and for special moment frames, a permissible height limit of 200 meters for This type of system is mentioned [5], so the range of models will be from 1 to 66 floors and just with a special moment frame system.

**Table 1:**Load rate of models

| Load type | Dead load | Live load |
|---|---|---|
| Floor + slab | 500 kg/m$^2$ | 200 kg/m$^2$ |

## DISCUSSION ON THE PERIODICITY OF MODELS

The periodicity of the first mode of the structure (fundamental periodicity) plays a large role in the calculation of the forces applied [7]. In this research, since the design of models and finding the true dynamical periodicity of the structure has been omitted due to the parametric nature of the research, the relations mentioned in the researches and valid regulations are used to calculate the fundamental periodicity of the building.

Chopra et al. [8] state equation (1) for the periodicity of frames, which can be increased up to a maximum of 40%. With the mentioned increase and considering another 25% increase, because they do not create a barrier between the frames for the movement of structural frames, Equation (2) can be achieved, which is also mentioned in Eurocode 8 and Iranian Standard 2800. These two regulations state that in general, if free vibration analysis is performed for moment frames, it is possible to consider up to 25% of the larger periodicity periods for spectral analysis.

But ASCE7-16 works differently. In the method of this regulation, the approximate empirical periodicity of the frame is obtained from Equation (3), the parameters of which are presented in Table (2). It also allows the use of Equation (4) for models up to 12 floors. This regulation states that in case of using dynamic spectral analysis and free vibration analysis, if the periodicity is greater than (Cu) multiplied by the approximate empirical periodicity according to the coefficients mentioned in Table (3), the maximum periodicity used can be considered Cu * Ta [1].

$$T_R=0.046H^{0.75} \tag{1}$$

$$T=0.08H^{0.75} \tag{2}$$

$$T_a = C_t H^x \tag{3}$$

$$T_a = 0.01N \tag{4}$$

**Table 2:**ASCE 7-10 values of approximate period parameters

| structure type | $C_t$ | X |
|---|---|---|
| Steel moment resisting Frame | 0.028 | 0.8 |
| Eccentrically braced steel frame | 0.03 | 0.75 |
| Concentrically braced steel frame | 0.02 | 0.75 |

**Table 3:**Coefficient for Upper Limit on Calculated Period

| Design Spectral Response Acceleration parameter at 1s ($S_{d1}$) | Coefficient, $C_u$ |
|---|---|
| >0.4 | 1.4 |
| 0.3 | 1.4 |
| 0.2 | 1.5 |
| 0.15 | 1.6 |
| <0.1 | 1.7 |

Rayleigh expresses the most accurate relation for finding the principal periodicity of the moment frame according to Equation (5). In this relation $w_i$ is part of the total weight of the structure assigned to the level i, $f_i$ is the lateral force at the level i, $\delta_i$ is the drift at the level i relative to the base due to the lateral force, g is the acceleration due to gravity and N is the total number of floors in the building. Young In his dissertation [9] using this relationship and through 24 regular and irregular three-dimensional models at different altitudes, the real periodicity period at different altitudes according to Figure (1) has been obtained. Comparing the obtained results with the results of Equation (3), he equated Equation (6) in which the last two fractions are the ratio of the mean height to the total height and the ratio of the mean length of the plane in the seismic direction under consideration to the total length (suitable for Irregular structures), suggests. This relationship shows that there is a 40 to 50% difference between the experimental period and the real one in all regular models (in a small number of irregular models it is inappropriate). Figure (2) shows the periodicity diagram based on the height of the structure due to equation(6).

$$T = 2\pi \sqrt{\sum_{i=1}^{N} w_i \delta_i^2 \Big/ g \sum_{i=1}^{N} f_i \delta_i} \tag{5}$$

$$T = 0.042(H)^{0.75} \left(\frac{H_{av}}{H}\right)^{0.35} \left(\frac{D_{av}}{D}\right)^{0.20} \tag{6}$$

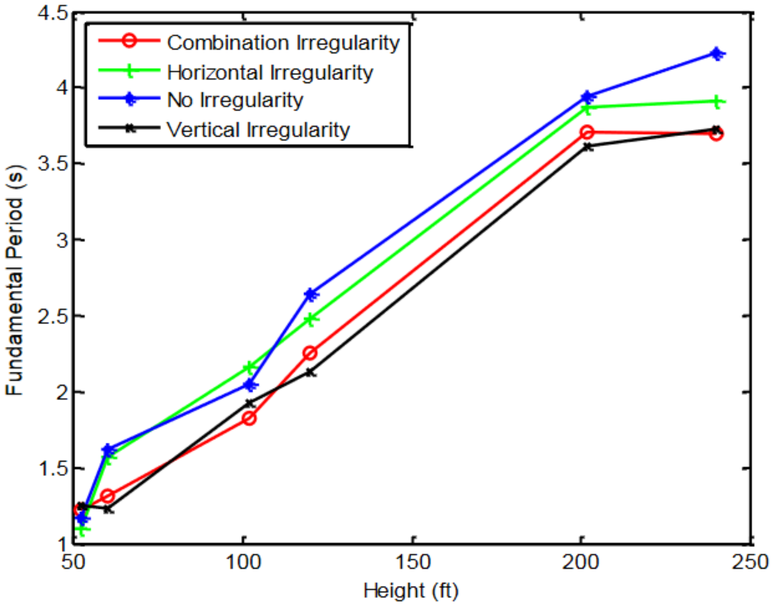

**Figure 1:**Precise periodicity of structural models with different irregular types and heights

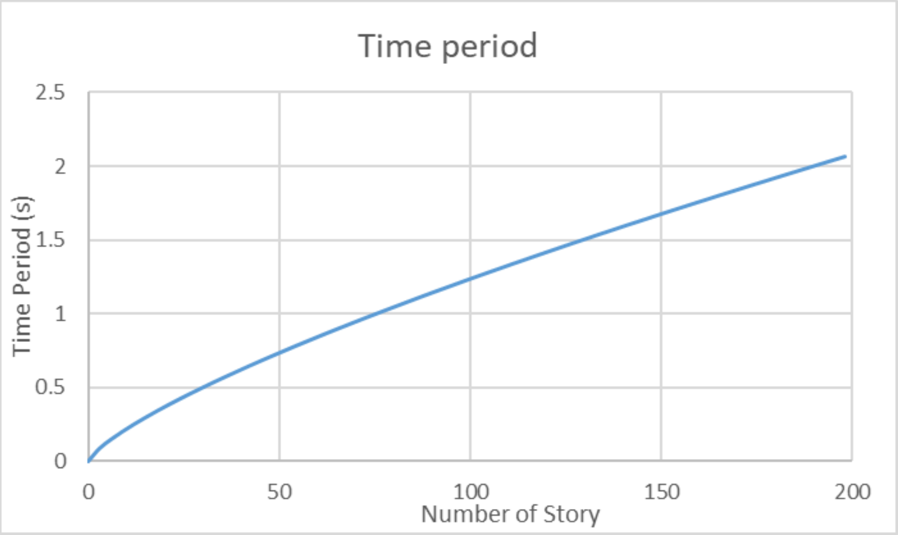

**Figure 2:**The amount of periodicity of the structure in relation to the height

## DETERMINE THE SHAPE OF THE SITE DESIGN SPECTRUM

The specific design spectrum of the site depends on the type of site soil and factors related to seismic intensity (proximity to faults, etc.) [3]. Tehran soil zoning according to the report of the Center for Geotechnical Studies and Material Strength of Tehran [10] and the location of selected sites on it, according to Figure (3), mainly from category II according to standard 2800 or class C according to NEHRP category (yellow areas in figure ( 3)) and the remaining southern parts of category III according to standard 2800 or class D according to soil classification NEHRP (reddish-colored areas in Figure (3)) [5, 6].

By providing soil information to the Iranian seismic hazard base and using the attached scientific report [11] as shown in Figure (4), spectral accelerations with a significance of 0, 0.2 and 1.0 seconds of sites according to Table (4) Is harvested. The 475-year uniform hazard spectra of the design as shown in Figure (6) can be plotted with the method in ASCE7-16 as shown in Figure (5). For this purpose, PGA is equal to the spectral acceleration during the zero-second period, SDS is equal to the spectral acceleration at the short-period, which according to the references is equal to 0.2 seconds, and SD1 is the spectral acceleration at Time is 1 second. Tables related to the exact values of periodicity and spectral acceleration calculated in each site for all frames of 1 to 66 floors under study are provided in the appendix.

**Table 4:**Seismic coordinates and characteristics of selected sites

| Site | longitude | latitude | soil type | SA(0.0) | SA(0.2) | SA(1.0) |
|---|---|---|---|---|---|---|
| 1 | 51.35 | 35.63 | D | 0.404 | 0.945 | 0.388 |
| 2 | 51.48 | 35.63 | D | 0.398 | 0.931 | 0.38 |
| 3 | 51.54 | 35.73 | C | 0.378 | 0.89 | 0.365 |
| 4 | 51.31 | 35.74 | C | 0.418 | 0.985 | 0.404 |
| 5 | 51.43 | 35.79 | C | 0.424 | 0.995 | 0.421 |
| 6 | 51.39 | 35.69 | C | 0.403 | 0.943 | 0.384 |

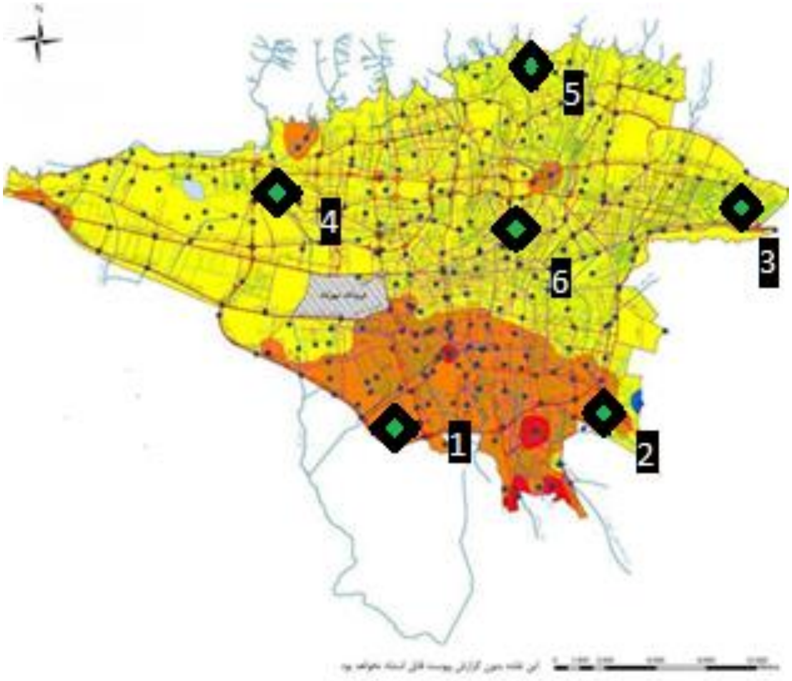

**Figure 3:**Soil zoning of Tehran [10]

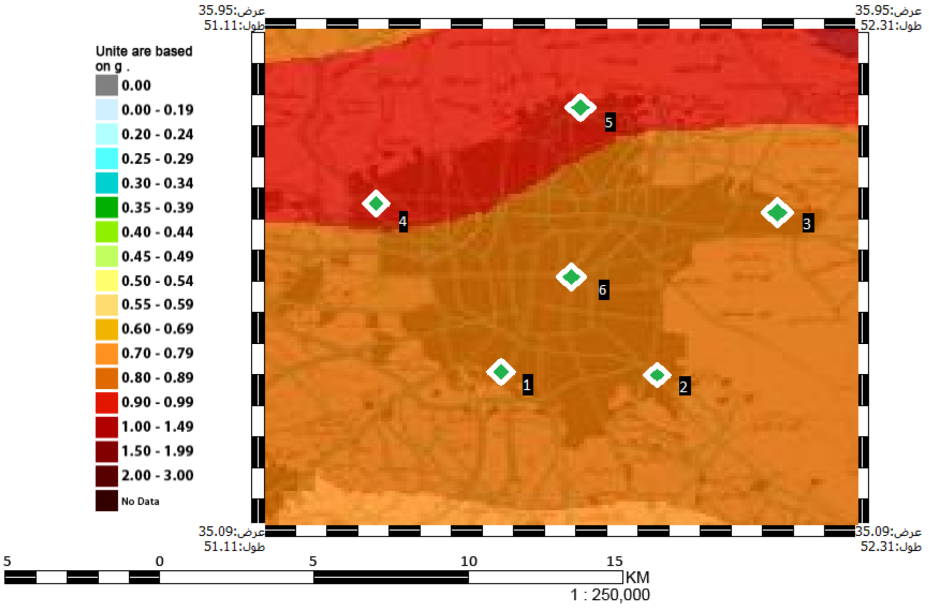

**Figure 4:**PGA zoning of Tehran with a return period of 475 years

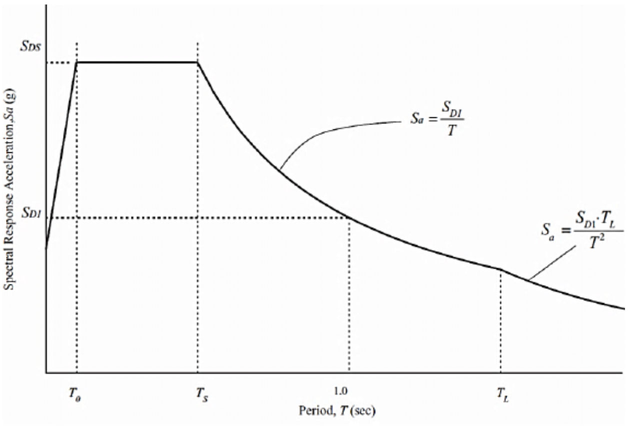

**Figure 5:**Seismic response spectrum plotting method[1]

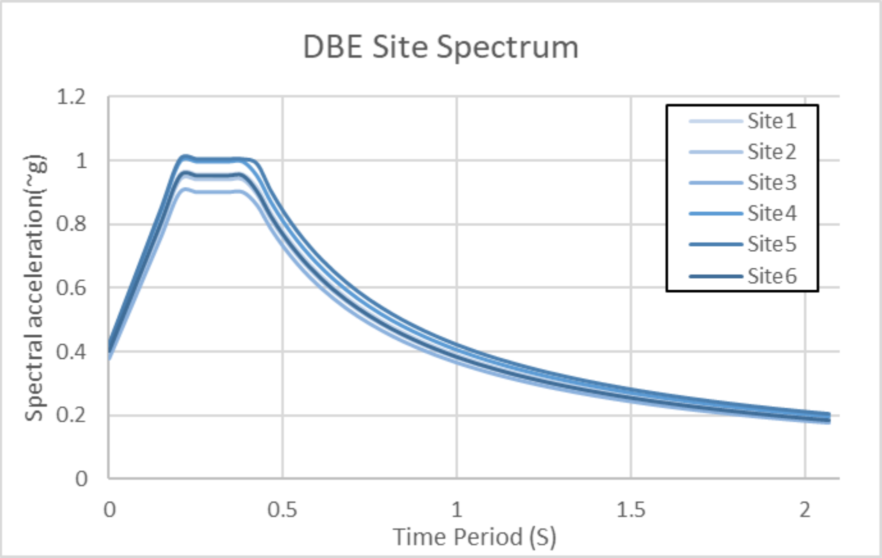

**Figure 6**-475:year uniform hazard spectrum obtained for use as seismic response spectrum at each site

## RESULTS

Although the periodicity in addition to height, to factors such as infrastructure area, length to width ratio of the structure, the stiffness of the beam and column sections, etc. [12] The three-dimensional model has a single aperture and in a way, according to its height and number of floors after equivalence, will have similar conditions to the area under study.

Using the periodicity of the building and the site spectrum, spectral accelerations are obtained and considering the coefficient of behavior (Ru) equal to 7.5 and the contribution of live load 20% in the seismic effective load (W) according to the proposal of ASCE7-16, using The Sa*W/Ru relation, the base shear of all frames is obtained according to Figure (7), which shows that for frames up to 7 floors, the base shear of the structure is the same for all constructions and for higher frames, the base shear rate increases. The base shear is reduced and is different for each site so that for the highest frame, a difference of 10% is observed in different sites.

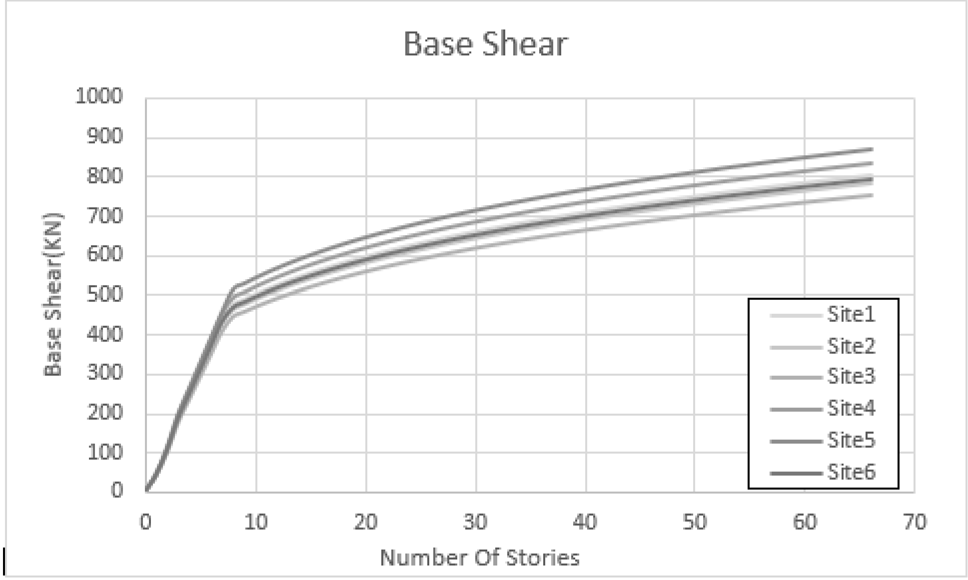

**Figure 7:**The cutting force of the base of the frames in relation to the height and in different constructions

Figure (8) shows the result of combined gravitational and earthquake forces according to the seismic combination mentioned in ASCE7-16 due to Equation (7), which adds each floor to the building in Site 1. as can be seen, for the buildings Up to 3 floors, The addition of each floor to the building increases the forces in the building more than the previous floors. This trend will be decreasing for 4 to 10 floor frames and almost constant for 11 to 66 floor frames. The typification of floors in the design of high-rise buildings according to this issue can lead the design to be more optimized.

$$1.2D + 1.0E + 1.0L + 0.2S \quad (7)$$

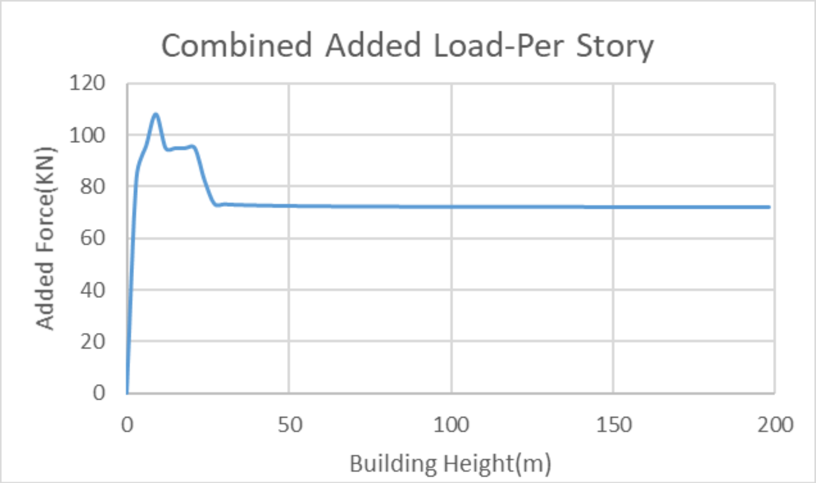

**Figure 8:**The result of multiplied forces added for each added floor of the building

The problem that results in the difference in the force added in each floor in Figure 8 is the seismic force, which depends on the seismic and geotechnical differences of the sites. Accordingly, in Figure (9), the base shear, which is added to the total base shear of the building in each site for each increased floor, is drawn for further study. This figure shows that the difference in the concept for different buildings is only visible for 3 to 9 floor frames, which is limited to less than 10% in the same range.

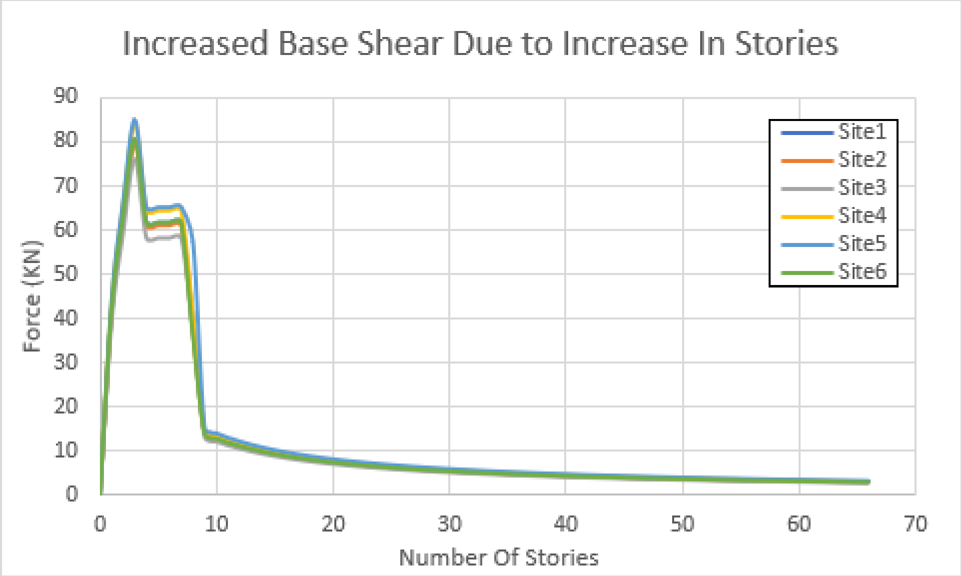

**Figure 9:**Basic shear force added for adding each floor of the building in different buildings

In Figure (10) using the combination of loads and SRSS estimation between gravitational and lateral forces, the result of base forces of the building with different number of floors for the frames in the first site is divided. The diagram shows that at the base of the building, with an error of less than 1%, it can be said that the result of the obtained forces has a linear relationship with the number of floors.

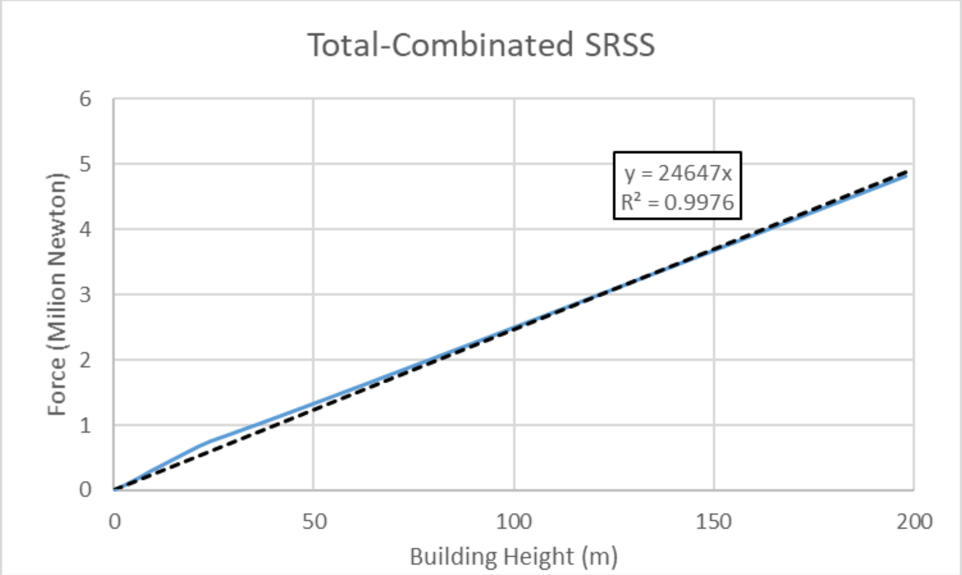

**Figure 10:**The result of the forces entering the base of the building with different number of floors

In order to obtain the relation of the slope of the conventional line in Figure (10), the slope of the line for different values of the total seismic effective gravitational load (D + 0.2L) is obtained and plotted in Figure (11). Each of the lines with regression error is less than 1% of the slope, which by drawing a line diagram of the slopes obtained from the effective seismic load in the entire substructure according to Figure (12), we reach a line with a slope of 15.395 . Therefore, it can be concluded that the result of building loads at its base for each possible height for special moment frames with a height of 3 meters per floor has a linear relationship with a fixed slope of 15.39 times the effective seismic load in the entire substructure.

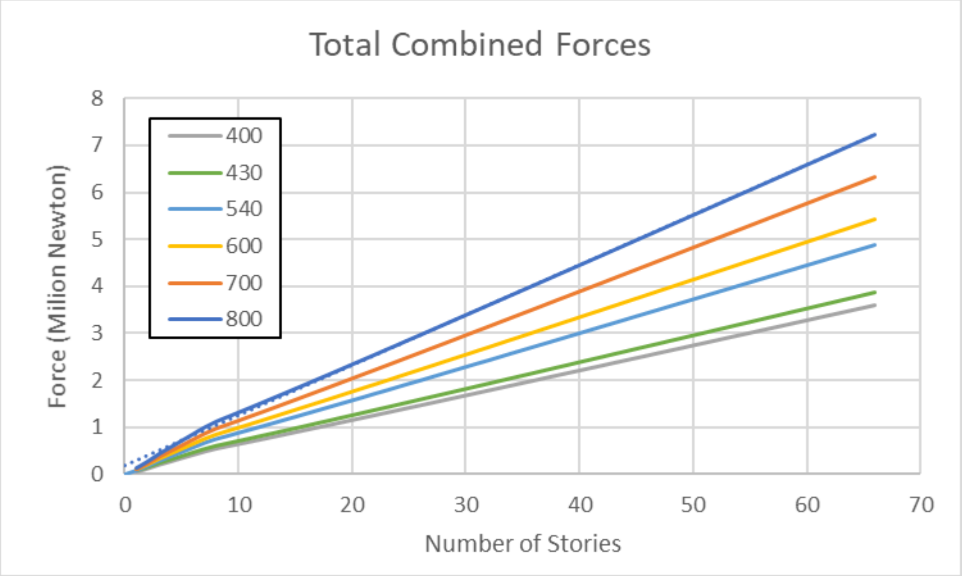

**Figure 11:** The result of combined loads at the building base for different seismic effective loads

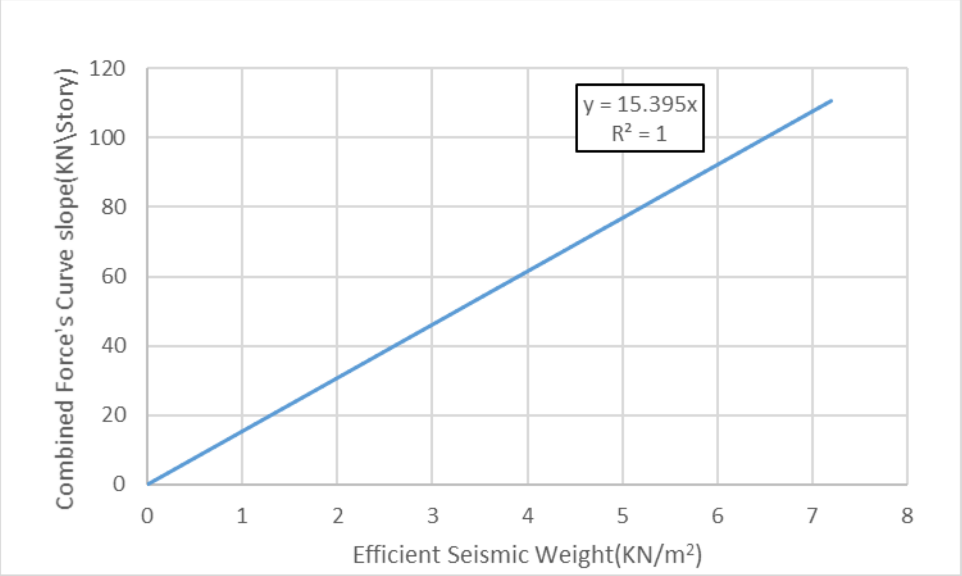

**Figure 12:** The slope of the building's base loads varies by the number of floors in exchange for effective loads

## CONCLUSIONS

Since each structural model in the form of a single-span model is able to be equivalent in any direction, in this paper with the aim of investigating the type of increase or decrease in the effects of gravity and seismic forces of moment frames, all models with special moment frame system with The heights of the 3 meters per floors were discussed. Previous researchs has shown that the periodicity of such systems, specially if building is regular, is higher than 40% larger than the above relation in Asce7-16 for its empirical approximate calculation, and therefore the ASCE7-16's relation for Approximate Time period can use the largest magnification coefficient, ie 1.4.

6 sites in different parts of Tehran were selected in terms of soil type and seismicity and their design spectrum was obtained. Finally, the spectral acceleration in the periodicity of each model according to the table in Appendix A was obtained and from there the base shear of the building was obtained. The results of study shows that:

- The final base shear of the models increases with increasing the number of floors, but for frames up to 7 floors, the basic shear force of the structure is the same for all buildings, and for higher frames, the rate of increase of the base shear decreases and up to 10% for each building is seen in different sites.
- The result of the added gravitational and seismic force added for each added floor depends on the number of floors in the building, and for buildings with up to 3 floors, adding each floor to the building increases the forces in the building more than the previous floors. This trend will be decreasing for 4 to 10 floor frames and almost constant from 11 to 66 floors. By drawing the mentioned trend only for added base shear of the building per floor for different sites in Tehran, the difference is obvious only for 3 to 9 floor frames, which is limited to less than 10% in the same range.

The result of combined gravitational and seismic forces at the base of the building is linearly related to the number of floors. The slope of the line can also be determined according to the effective seismic load (D + 0.2L). Thus, for example, in this study, the slope of the output line of the base loads relative to the number of floors of the building is 15.35 times the effective seismic load.

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## APPENDIX

| Structural specifications | | | Spectral specifications | | | | | |
|---|---|---|---|---|---|---|---|---|
| Stories | Height | Period | Sa(Site1) | Sa(Site2) | Sa(Site3) | Sa(Site4) | Sa(Site5) | Sa(Site6) |
| 0 | 0 | 0.000 | 0.404 | 0.398 | 0.378 | 0.418 | 0.424 | 0.403 |
| 1 | 3 | 0.089 | 0.646 | 0.636 | 0.607 | 0.671 | 0.679 | 0.644 |
| 2 | 6 | 0.150 | 0.811 | 0.798 | 0.763 | 0.844 | 0.853 | 0.809 |
| 3 | 9 | 0.204 | 0.955 | 0.941 | 0.899 | 0.995 | 1.006 | 0.953 |
| 4 | 12 | 0.253 | 0.955 | 0.941 | 0.899 | 0.995 | 1.006 | 0.953 |
| 5 | 15 | 0.299 | 0.955 | 0.941 | 0.899 | 0.995 | 1.006 | 0.953 |
| 6 | 18 | 0.343 | 0.955 | 0.941 | 0.899 | 0.995 | 1.006 | 0.953 |
| 7 | 21 | 0.385 | 0.955 | 0.941 | 0.899 | 0.995 | 1.006 | 0.953 |
| 9 | 27 | 0.464 | 0.836 | 0.818 | 0.786 | 0.870 | 0.907 | 0.827 |
| 10 | 30 | 0.502 | 0.772 | 0.756 | 0.726 | 0.804 | 0.838 | 0.764 |
| 11 | 33 | 0.540 | 0.719 | 0.704 | 0.676 | 0.749 | 0.780 | 0.711 |
| 12 | 36 | 0.576 | 0.673 | 0.660 | 0.634 | 0.701 | 0.731 | 0.667 |
| 13 | 39 | 0.612 | 0.634 | 0.621 | 0.597 | 0.660 | 0.688 | 0.628 |
| 15 | 45 | 0.681 | 0.570 | 0.558 | 0.536 | 0.593 | 0.618 | 0.564 |
| 16 | 48 | 0.715 | 0.543 | 0.532 | 0.511 | 0.565 | 0.589 | 0.537 |
| 17 | 51 | 0.748 | 0.519 | 0.508 | 0.488 | 0.540 | 0.563 | 0.513 |
| 18 | 54 | 0.781 | 0.497 | 0.487 | 0.467 | 0.517 | 0.539 | 0.492 |
| 19 | 57 | 0.813 | 0.477 | 0.467 | 0.449 | 0.497 | 0.518 | 0.472 |
| 20 | 60 | 0.845 | 0.459 | 0.450 | 0.432 | 0.478 | 0.498 | 0.454 |
| 21 | 63 | 0.877 | 0.443 | 0.434 | 0.416 | 0.461 | 0.480 | 0.438 |
| 22 | 66 | 0.908 | 0.427 | 0.419 | 0.402 | 0.445 | 0.464 | 0.423 |
| 23 | 69 | 0.938 | 0.413 | 0.405 | 0.389 | 0.430 | 0.449 | 0.409 |
| 24 | 72 | 0.969 | 0.400 | 0.392 | 0.377 | 0.417 | 0.435 | 0.396 |
| 25 | 75 | 0.999 | 0.388 | 0.380 | 0.365 | 0.404 | 0.421 | 0.384 |
| 26 | 78 | 1.029 | 0.377 | 0.369 | 0.355 | 0.393 | 0.409 | 0.373 |

| | | | | | | | | |
|---|---|---|---|---|---|---|---|---|
| 27 | 81 | 1.058 | 0.367 | 0.359 | 0.345 | 0.382 | 0.398 | 0.363 |
| 28 | 84 | 1.088 | 0.357 | 0.349 | 0.336 | 0.371 | 0.387 | 0.353 |
| 29 | 87 | 1.117 | 0.347 | 0.340 | 0.327 | 0.362 | 0.377 | 0.344 |
| 30 | 90 | 1.145 | 0.339 | 0.332 | 0.319 | 0.353 | 0.368 | 0.335 |
| 31 | 93 | 1.174 | 0.331 | 0.324 | 0.311 | 0.344 | 0.359 | 0.327 |
| 32 | 96 | 1.202 | 0.323 | 0.316 | 0.304 | 0.336 | 0.350 | 0.319 |
| 33 | 99 | 1.230 | 0.315 | 0.309 | 0.297 | 0.328 | 0.342 | 0.312 |
| 34 | 102 | 1.258 | 0.308 | 0.302 | 0.290 | 0.321 | 0.335 | 0.305 |
| 35 | 105 | 1.286 | 0.302 | 0.296 | 0.284 | 0.314 | 0.327 | 0.299 |
| 36 | 108 | 1.313 | 0.295 | 0.289 | 0.278 | 0.308 | 0.321 | 0.292 |
| 37 | 111 | 1.341 | 0.289 | 0.283 | 0.272 | 0.301 | 0.314 | 0.286 |
| 38 | 114 | 1.368 | 0.284 | 0.278 | 0.267 | 0.295 | 0.308 | 0.281 |
| 39 | 117 | 1.395 | 0.278 | 0.272 | 0.262 | 0.290 | 0.302 | 0.275 |
| 40 | 120 | 1.421 | 0.273 | 0.267 | 0.257 | 0.284 | 0.296 | 0.270 |
| 41 | 123 | 1.448 | 0.268 | 0.262 | 0.252 | 0.279 | 0.291 | 0.265 |
| 42 | 126 | 1.474 | 0.263 | 0.258 | 0.248 | 0.274 | 0.286 | 0.260 |
| 43 | 129 | 1.500 | 0.259 | 0.253 | 0.243 | 0.269 | 0.281 | 0.256 |
| 44 | 132 | 1.527 | 0.254 | 0.249 | 0.239 | 0.265 | 0.276 | 0.252 |
| 45 | 135 | 1.553 | 0.250 | 0.245 | 0.235 | 0.260 | 0.271 | 0.247 |
| 46 | 138 | 1.578 | 0.246 | 0.241 | 0.231 | 0.256 | 0.267 | 0.243 |
| 47 | 141 | 1.604 | 0.242 | 0.237 | 0.228 | 0.252 | 0.262 | 0.239 |
| 48 | 144 | 1.630 | 0.238 | 0.233 | 0.224 | 0.248 | 0.258 | 0.236 |
| 49 | 147 | 1.655 | 0.234 | 0.230 | 0.221 | 0.244 | 0.254 | 0.232 |
| 50 | 150 | 1.680 | 0.231 | 0.226 | 0.217 | 0.240 | 0.251 | 0.229 |
| 52 | 156 | 1.730 | 0.224 | 0.220 | 0.211 | 0.233 | 0.243 | 0.222 |
| 53 | 159 | 1.755 | 0.221 | 0.216 | 0.208 | 0.230 | 0.240 | 0.219 |
| 54 | 162 | 1.780 | 0.218 | 0.213 | 0.205 | 0.227 | 0.237 | 0.216 |
| 55 | 165 | 1.805 | 0.215 | 0.211 | 0.202 | 0.224 | 0.233 | 0.213 |
| 56 | 168 | 1.829 | 0.212 | 0.208 | 0.200 | 0.221 | 0.230 | 0.210 |
| 57 | 171 | 1.854 | 0.209 | 0.205 | 0.197 | 0.218 | 0.227 | 0.207 |
| 58 | 174 | 1.878 | 0.207 | 0.202 | 0.194 | 0.215 | 0.224 | 0.204 |
| 59 | 177 | 1.902 | 0.204 | 0.200 | 0.192 | 0.212 | 0.221 | 0.202 |
| 60 | 180 | 1.926 | 0.201 | 0.197 | 0.189 | 0.210 | 0.219 | 0.199 |
| Structural specifications | | | Spectral specifications | | | | | |
| Stories | Height | Period | Sa(Site1) | Sa(Site2) | Sa(Site3) | Sa(Site4) | Sa(Site5) | Sa(Site6) |
| 62 | 186 | 1.974 | 0.197 | 0.192 | 0.185 | 0.205 | 0.213 | 0.194 |
| 63 | 189 | 1.998 | 0.194 | 0.190 | 0.183 | 0.202 | 0.211 | 0.192 |
| 64 | 192 | 2.022 | 0.192 | 0.188 | 0.181 | 0.200 | 0.208 | 0.190 |
| 65 | 195 | 2.046 | 0.190 | 0.186 | 0.178 | 0.198 | 0.206 | 0.188 |
| 66 | 198 | 2.069 | 0.188 | 0.184 | 0.176 | 0.195 | 0.203 | 0.186 |