Non-Linear Behaviour of Staggered Steeltruss System Under Seismic And Wind Analysis

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Abstract- *In this paper, preliminary design of high-rise steel buildings with staggered truss system in G+10, G+20 and G+30 building provided in which Staggered truss is provided at 2nd,3rd,6th,8th,11th,13th,16th,19th,21st,25th,27th,29th, and 31st storey. P-Delta analysis is provided which is nonlinear static analysis method. Staggered truss system is a prospective steel structure system for multi-story and high-rise buildings. The staggered truss framing system arose from the use of system design techniques to improve efficiency in building construction. Staggered truss systems have proved to be effective in integrating the structural and mechanical requirements. In addition, cost reductions arising from reduced steel tonnage and reduced building volume may be achieved from the use of these framing methods.*

The parameters such as the structural truss type, arrangement of the trusses are varied, and their influences on seismic behaviours of the system are studied. And based on the test results, some indices of seismic behaviours of the system, such as yield load, deformation and strength are analyzed.

Keywords- Staggered Truss, P-Delta; nonlinear static analysis; Seismic Loading, Truss, Lateral stiffness

I. INTRODUCTION

Staggered truss system is a prospective steel structure system for multi-story and high-rise buildings. The staggered truss framing system arose from the use of system design techniques to improve efficiency in building construction. Staggered truss systems have proved to be effective in integrating the structural and mechanical requirements. In addition, cost reductions arising from reduced steel tonnage and reduced building volume may be achieved from the use of these framing methods. The purpose of this project is analytical investigation on the behaviour of an 8-storey steel staggered-truss system using the ETABS software. The parameters such as the structural truss type, arrangement of the trusses is varied, and their influences on seismic behaviours of the system are studied. And based on the test results, some indices of seismic behaviours of the system, such as yield load, deformation and strength are analysed.

The staggered arrangement of the storey-high trusses placed at alternate levels on adjacent column lines allows an interior floor space of twice the column spacing to be available for freedom of floor arrangements. To resist gravity loads, the floor system may be considered to be a series of simple spans or continuous for two columns spacing. As a continuous system, the floor members rest on the top chord of one truss and extend to the bottom chords of the two adjacent trusses.

The staggered-truss system (STS) is a new concept in structural steel framing for high-rise buildings, which was developed in Massachusetts Institute of Technology in 1960s. This system is efficient for midrise apartments, hotels, motels, dormitories, hospitals, and other structures for which a low-floor to-floor height is desirable. As shown in Figure 1.1, the system consists of a series of storey-high trusses spanning the total width between two rows of exterior columns and arranged in a staggered pattern on adjacent column lines. With the columns only on the exterior walls of the building, the usual interior columns are omitted, thus providing a full width of column-free area.

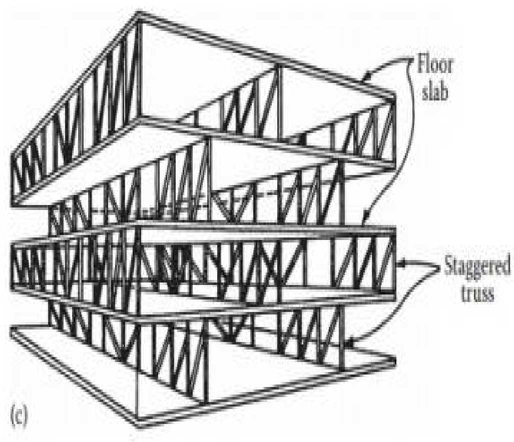

Figure 1. Illustration of a staggered truss system

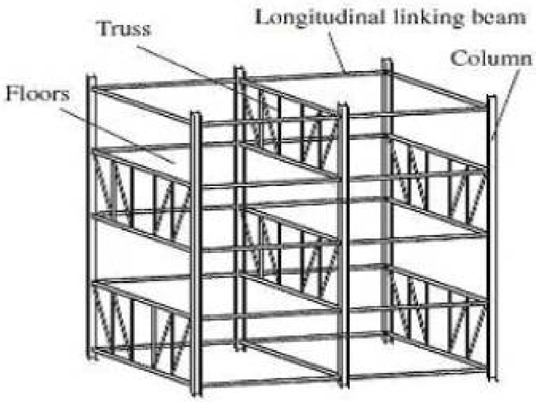

Figure 2. (a) Hybrid truss and (b) open-web truss

Accordingly, by the review of the researchers on PT slab and Flat slab building the concerning factors for the structural design of such buildings are as,

1. S. Simasathien1, S-H. Chao, K. Moore, and T. Okazakipresented**"Modified Structural Layouts for Staggered Truss Framing Systems Used in Seismically Active Areas"** The steel Staggered Truss Framing (STF) system is a highly economical and efficient steelframing system that accommodates generic architectural and structural requirements for mid- to high-rise buildings. Due to the attributes of enabling small floor-to-floor height, large column free spaces, reduced number of columns, efficient use of material, light weight, reduced size and load requirements for the foundation, high lateral stiffness, rapid construction, and low overall cost, STFs have become a popular system in regions of low seismicity. Although STFs were originally developed for low seismic regions, the high lateral stiffness and light weight make this system attractive for use in high seismic regions. However, very limited studies have been conducted on the behavior of STFs under strong earthquake ground motions. A key to the lateral load resisting mechanism of STFs is the active participation of the floor diaphragms (typically consists of prestressed hollow-core planks) to transfer the inertial forces cumulating in a staggered manner across the height of the structure.

2.SivajiAtturi, E. Arunakanthipresented **"A Study on Staggered Truss Frame Steel Structural Systemthe"** The staggered truss system is a new concept in structural steel framing for high rise buildings. The system consists of a series of story-high trusses spanning the total width between two rows of exterior columns and arranged in a staggered pattern on adjacent column lines. The arrangement of story-high trusses in a staggered pattern at alternate columnlines provide large column-free areas for room layouts. The interaction of the floors, trusses, and columns makes the structure perform as a single unit, thereby taking maximum advantage of the strength and rigidity of all the components simultaneously. Each component performsits particular function, totally dependent upon the others for its performance. The staggered truss system of steel framing has become an economical system for high-rise, high-density occupancy buildings.

3.Xuhong Zhou, YongjunHe, Lei Xu, Qishi Zhou presented **"Experimental study and numerical analyses on seismic behaviors of staggered-truss system under low cyclic loading"** An experimental investigation on the behavior of an 8-storey steel staggered-truss system with a 18-scaled model under reversed low cyclic loading is presented in this paper. The ground floor trusses should be arranged for the staggered-truss system with seismic requirement, and the number of trusses on the ground floor should not be less than half of the total number of the transverse frames. It is suitable for staggered-truss system to adopt hybrid truss and longitudinal corridor set at or nearby the span center of truss. With increase of the open-web panel length of truss, the top lateral displacement and ductility of the structure increase, but the lateral displacement when the vertical web members of the open-web panels start to fail decreases gradually, and the ultimate displacement grows more rapidly than the ductility. On the condition that structure functions are satisfied, the open-web panel length of truss should be as small as possible to enhance the seismic behaviors of the system.

1.1 Advantages

i. Columns have minimum bending moments due to gra vity and wind loads, because of the cantilever action of the double-planar system of framing.
ii. Columns are oriented with their strong axis resisting l ateral forces in the longitudinal direction of the buildi ng.
iii. Maximum live load reductions may be realized becau se tributary areas may be adjusted to suit code require ments.
iv. Foundations are on column lines only and may consis t of two strip footings. Becausethe vertical loads are c oncentrated at a few column points, less foundation formwork isrequired.
v. Drift is small, because the total frame is acting as a st iff truss with direct axial loads only acting in most str uctural members. Secondary bending occurs only in t he chords of the trusses.

1.2 Aim

The aim of this master's dissertation is to provide knowledge relevant for preliminary design of high-rise steel buildings with staggered truss system in G+10, G+20 and G+30. The methodology developed can be used in an early stage to simplify the preliminary design of the building. Different model simplifications and idealisations are studied, with the aim of finding appropriate and simple models and thus reducing the need of advanced FE-models. If such structural system and its general properties can be determined in a reliable and appropriate way in an early stage, the construction process and size of the usable surface can be estimated better. This leads to a more reliable economy for the project which will benefit both the entrepreneur and the developer. Better knowledge of such structural system in an early stage of the project also simplifies upcoming design calculations.**Staggered** truss is provided at 2^{nd},3^{rd},6^{th},8^{th},11^{th},13^{th},16^{th},19^{th},21^{st},25^{th},27^{th},29^{th}, and 31^{st} storey.

II. OBJECTIVES

Objectives of study:

The main objective is to develop a comparative result in G+10, G+20 and G+30 steel building with staggered truss systems incorporated in it. The methodology is based on idealized calculations and idealized FE-models, for that ETABS 2018 is used for modeling purpose. The load calculation methods are used as per Indian standard codes. Following are the objectives of this project.

1. To study behaviour of staggered trusses subjected to critical seismic zone and wind speed.
2. To check results of G+10, G+20, G+30 high rise steel structure with staggered truss subjected to lateral loading.
3. To determine the base shear, overturning moment, time period, natural frequency and mode shapes for all three high rise building.
4. To investigate the seismic performance of a multi-story steel frame building

Analyze behavior of structure with different height variation with staggered truss configuration using Response Spectrum analysis and time history analysis

III. METHODOLOGY

Although modular technology has been around for decades and established low rise examples have existed for over 20 years, the technology is relatively new in high rise construction and very limited examples exist that have been completed or are under construction. As such, large data set analysis is not currently possible and analysis must be limited to the few dozen projects available for review around the world. In light of this data set, the methodology of research primarily relies upon literature review, interviews, case studies and financial analysis based upon scenarios of available construction data.

Buildings with staggered truss are analyzed with G+10,G+20,G+30 storey structure in which seismic and wind analysis performed with high grade concrete in building, Also, nonlinear dynamic time history analysis is also performed get severe situation condition in the structure.

IV. MODELING AND ANALYSIS

4.1 Material Properties and Section Properties:

Concrete grade: M25
Steel grade: FE415, FE500
Structural Steel grade: FY250

4.2. Load calculations:

Dead load and live load calculation on slab (As Per IS 875-2015 Part-1&Part-2 clause 3.1Table 1):
Dead load calculation (from IS 875 part 1):
Dead Load = 1.5 KN/m^2
Live Load = 2 KN/m^2

4.3 Earthquake load (IS-1893-Part: 1-2016):

The building location where seismic Zone is IV with factor0.36. Since it is a residential building, which is having importance factor 1. A Lateral force resisting system in which RC SMRF with response reduction factor (R) 5 is taken. Project building is located on soft soil site. For time history analysis, Fast Nonlinear Analysis Method is used to get accurate results. Ground motion data of Loma Prieta earthquake is taken which is having earthquake magnitude of 6.9 Mw, a maximum Modified Mercalli intensity of IX (Violent).

4.4 Wind load calculations:

Wind loads is calculated in accordance with IS 875: Part 3.Project is considered to be located in location where basic wind speed is 44 m/sec with fairly level topography with mean return period of 50 years is considered for which the k1factor will be 1. Since the project building is considered to having some surrounding buildings of sizes up to 10 m in height with or without a few isolated tall structures, hence it will be in terrain category is III.

4.5. Modeling in ETABS 2018- version 18.1.1

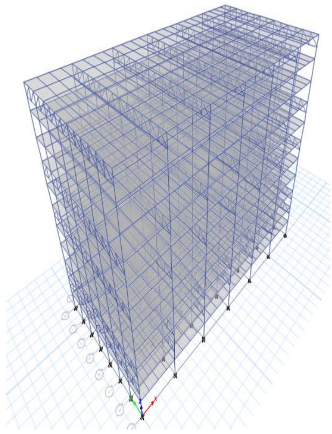

Figure 3. G+10 Building with staggered truss

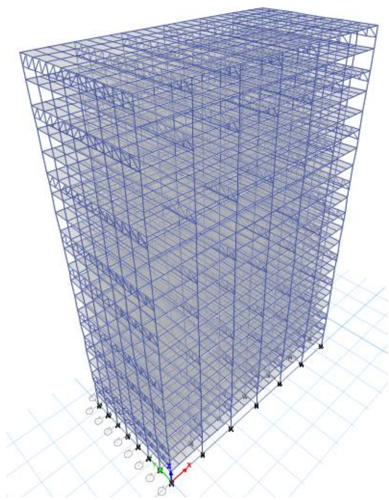

Figure 4. G+20 Building with staggered truss

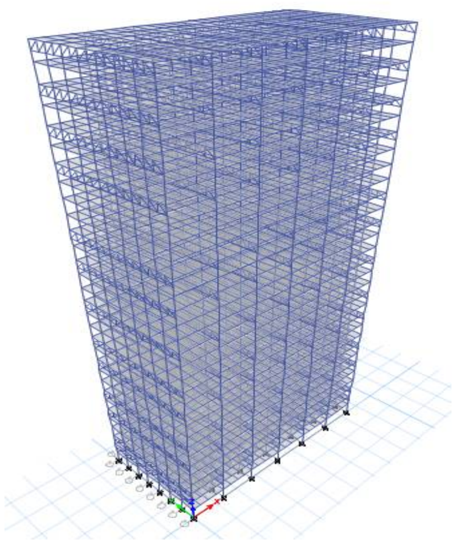

Figure 5. G+30 Building with staggered truss

V. RESULTS AND DISCUSSION

5.1 Displacement :

The maximum allowable displacement for G+10 building, in earthquake it will be 132mm and in wind 66mm, for G+20 building, in earthquake it will be 252mm and in wind 126mm, in earthquake it will be 372mm and in wind 186mm, Figure shows the maximum displacement for dynamic analysis i.e., response spectrum analysis, since it's a steel structure there will be definitely there will be more displacement in earthquake but as seen in wind values, displacement is less because it is completely resisted by provided truss. As the building height is increases value of displacement increases due to more inertia force induced in the structure. G+30 building shows maximum displacement in both wind and earthquake cases and the values are 5464mm and 3683mm respectively. From this result it can be say that steel structure with staggered truss up to 10 storey can sufficiently shows displacement in control or resist enough amount of forces for deflection. As the steel structure is more ductile, displacement will be high.

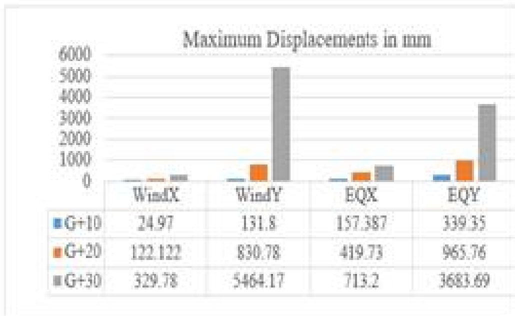

Figure 6. Maximum horizontal displacement due to lateral force

5.2 Drift :

According to the storey drift limitation given in IS 1893 (Part I): 2016 each storey drifts must be limited to 0.004 times the storey height. In case of building with staggared truss system shows variable drift values at the base of the structure, as the height of building increases it might show difference in drift values in incremental manner. For both X and Y direction earthquake, gives maximum drift at base, as shown in below table. Also in below table, values of drift can be determining and observe the difference in drift values as storey increases.

If we observe the result carefully it can be seen that drift at EQX direction is more than the EQY because of staggered truss arrangement is such a way that the it can resist more drift in EQY direction. If we see interstorey drift table wherever trusses are provided storey drift is less than where truss is not given. It can be concluded that this truss system helps in drift reduction.

Table 1.Drift in structure due to lateral force

Storey	G+10		G+20		
	EQ-X	EQ-Y	EQ-X	EQ-X	
Terrace				Terrace	
Story30				Story30	
Story29				Story29	
Story28				Story28	
Story27				Story27	
Story26				Story26	
Story25				Story25	
Story24				Story24	
Story23				Story23	
Story22				Story22	
Story21/Terrace			0.001887	Story21/Terrace	
Story20				0.002553	Story20
Story19				0.00333	Story19
Story18				0.004113	Story18
Story17				0.004861	Story17
Story16				0.005558	Story16
Story15				0.006195	Story15
Story14				0.006772	Story14
Story13				0.007292	Story13
Story12				0.007754	Story12
Story11/Terrace		0.002253	0.001368	0.008163	Story11/Terrace
Story10		0.003118	0.008968	0.008517	Story10
Story9		0.004044	0.010716	0.00882	Story9
Story8		0.004888	0.003012	0.00907	Story8
Story7		0.005585	0.014677	0.009257	Story7
Story6		0.006111	0.003844	0.00936	Story6
Story5		0.006434	0.022813	0.009329	Story5
Story4		0.006494	0.021949	0.009057	Story4
Story3		0.006141	0.002349	0.00832	Story3
Story2		0.005024	0.004144	0.006644	Story2
Story1		0.00237	0.019277	0.003061	Story1

5.3Overturning Moment :

The location of center of mass and center of stiffness in the structure is very important in overturning moment. As the center of mass and center of stiffness far from each other, maximum will be the overturning moment so as torsional moment in the structure. To avoid higher torsional moment in the structure IS 1893:2016 (Part-I) has given certain calculation in clause 7.8. As per this clause, eccentricity between center of mass and center of stiffness shall be maintained. Also, some types of vertical irregularities also cause overturning moment in the structure.

From above Fig., it can be observed that the value of overturning moment will be more in steel structure and as the building height keeps on increasing it will cause torsion failure in the structure. But to tackle this issue bracing should be provided in longer direction. From above fig. it is clear that value of overturning moment is more in G+30 building. It is better to construct upto G+10 storey steel building if bracings are avoided in the structure otherwise failure of will be caused if building located in earthquake or wind prone region.

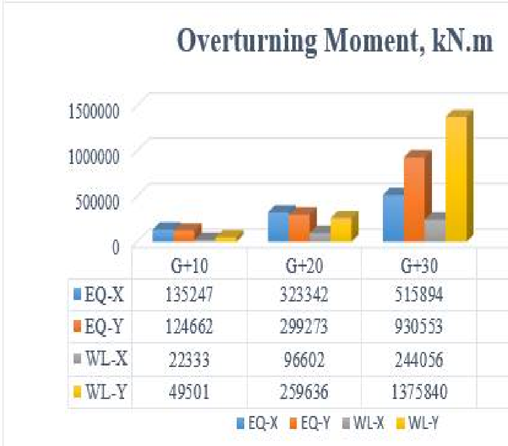

Figure 7. Overturning moment comparison

5.4Base Shear :

Table 2.Base in structure due to earthquake

	G+10	G+20
Base shear EQX (kN)	4948.61	5876.76
Base shear EQY (kN)	4153.74	4155.03
Dead Load (kN)	50234.59	95836.16
Live Load (kN)	19404	37044
% of earthquake (EQX)	8.9	5.6
% of earthquake (EQY)	7.5	3.95

Table 3. Base in structure due to wind

	G+10	G+20
Base shear WLX (kN)	1090.05	2366.55
Base shear WLY (kN)	2180.11	4733.11

VI. DISCUSSION

In case of displacement, earthquake limits are mentioned above, but due to absence of bracings in the structure, displacement keeps on increase as the height of the structure increases. In case of wind displacements, G+10 steel structure shows controlled displacement but in G+20 & G+30 structures displacement is around 60 to 70% more which will definitely be the reason of failure of structure in serviceability. To reduce the displacements, lateral bracings / elevations bracing needs to be provided in longer direction of building.

Also staggered truss system caused discontinuity in load transfer mechanism.

Drift limit is 0.004 x storey height as per IS 1893-2016, but at certain locations/storey specifically where truss is not given, drift value is decreased in each building.

If continuity in truss is given, then drift values will be in limit. Also, as the height is increased, drift becomes more, so height is also be the most affecting parameter for the drift. Around 30 to 40% drift values are increasing as the height of the structure increased.

Overturning moment is completely depend upon self-weight of structure and lateral road resisting system provided in the building. From values of overturning moment it can be conclude that due to absence of bracings and also light weight structure, overturning moment is increased as the height of structure is increased.

As this structure is regular and uniform loading applied structure is showing ideal behaviour mentioned in IS 1893-2016, usually in steel structure behaviour is depend on which type of members, type of structural system, bracing system, flooring system.

As the time period increased, structure to be considered as more ductile/flexible. From the table of time period, it can be seen that G+30 shows maximum time period which can be considered as ductile behaviour. Also, the reason for more time period value is mass as well as stiffness of the structure. Time value period increased about 40 to 50% as storey increased in the building.

Base shear is the parameter which is most important in any structure which is subjected to lateral loads. In case of wind, values of base shear is in limit since there will be wind pressure from the ground level. As the building height increases, base shear is also increased. Base shear becomes doubled when height of structure is changed.

Since our structure is steel structure staggered truss system, base shear due to earthquake will be definitely on higher side. Percentage of the earthquake induced in the structure is mentioned in the table of the base shear. Due to less amount of self-weight base shear increased drastically in all the structures.

VII. CONCLUSION

1. Due to staggered truss system in the structure, there is variation in loading at each level due to which draft variation observed very much in each building. At storey where trusses are given, drift values are in limit at least upto G+10 storey. After that drift values are increased drastically. To reduce drift, plan bracings can be provided to avoid serviceability failure.
2. Displacement is major factor which can cause severe damage in the structure. Due to absence of elevation bracings, values of displacements are above limit of displacement combination of bracing will be a better option in such structures.
3. If in any steel structures, staggered bracings are using, then upto 10 storey building behaviour will be on safer side or appropriate as per requirements of Indian standard codal provisions.
4. Staggered truss system in earthquake or wind prone region will or might be less effective until and unless bracings shall be given in structure.
5. Base shear and over turning moment increase due to earthquake as the building height is increased which definitely be the matter of concern if such systems are not well analysed and design proper elements.
6. More the height of the steel structure with staggered bracings, more will be the drift, displacement, base shear and overturning moment.
7. As the building load distribution is uniform, structure shows more than 75% translation modal mass participation in first two model. More than 90% of the mass is participated after the 8^{th} mode of vibration which shows an ideal behaviour of structure as per Indian standard provisions. Time period increases as the height of the structure increased which conclude ductility in the structure increase as slenderness of structure increased

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