ESCUELA DE CONSTRUCCIÓN CIVIL
FACULTAD DE INGENIERÍA
Revista de la Construcción
Journal of Construction

Research Article

Construction sequence analysis of multi-storey setback building placed in slope with p-delta and time-dependent effects

G.C. Balaji[1], **S.S.Vivek***

[1] School of Civil Engineering, SASTRA Deemed University, Thanjavur(India), gcbalaji24@yahoo.in
[2] School of Civil Engineering, SASTRA Deemed University, Thanjavur(India), vivek@civil.sastra.edu
*Correspondence: vivek@civil.sastra.edu

Received:07.01.2022; **Accepted:**13.08.2022; **Published:**30.08.2022

Citation: Balaji, G.C. and Vivek, S.S. (2022).Construction sequence analysis of multi-storey setback building placed in slope with p-delta and time-dependent effects. Revista de la Construcción. Journal of Construction, 21(2), 408-426. https://doi.org/10.7764/RDLC.21.2.408.

Abstract: Analysis and design of the structure are the most critical steps in the pre-construction steps involved. Nowadays, as technology is well developed, there is plenty of software available to carry over the analysis and design of any structures in a short period. In every software, the building model with all storey will be modelled, and loads are applied to the modelled structure on respective members, and their responses will be studied for the whole structure. But in reality, the building will be constructed in sequence as a step-by-step process, i.e., storey after storey with their respective loads, which may produce different responses. This analysis with sequential loading at each step is called Construction Sequence Analysis (CSA). In the present project work, the ten-storey setback building with a built-up area of 25m x 30m placed on the slope of 10°, assumed to be situated in Darjeeling, is modelled in ETABS software. The loads, namely gravity and lateral loads are applied to the developed model. Then the model is analyzed for different loads and their combinations as prescribed by IS codes. The combinations that produce high response are selected and dead load in those combinations are replaced with three modes: CSA without P-Delta effect, CSA with P-Delta effect, and CSA with P-Delta and Time-dependent effects combined. Thus the model is analyzed with these three additional combinations along with selected conventional load combinations. The various comparisons such as storey displacement, and storey drift between these four combinations of analysis were studied, and results were discussed. The building design is also done based on the analysis performed.

Keywords: CSA, P-Delta, time-dependent, storey displacement, ETABS.

1. Introduction

Construction sequence analysis (CSA) is a novel method of structural analysis which could relate the construction activities and events at par with the real-time field scenario. In the conventional method of analysis, the total loads would be applied directly to the developed 3D or 2D model using the software. Whereas in the CSA method, the stages of construction were first studied based on the loads applied based on the sequential mode of construction events and activities. Further, in the CSA method, P-delta effects based on the higher storey and dynamic analysis could also be performed for the lateral load effects. Hence in the CSA method, it could be possible to include the short-term effects as well as long-term effects on structures. The short-term effect includes elastic deformation of the structural members and their joints. In long-term effects, the deflection due to creep and shrinkage is also considered while performing analysis and design. If the primary loads considered namely dead and live loads were very critical and should be computed & analysed carefully. Some loads namely transient loads such as live loads which may be on or off during the construction and service stages also catered effectively using the CSA method of analysis. The typical pictorial load representation of the conventional and CSA method is shown(Figures 1 and 2).

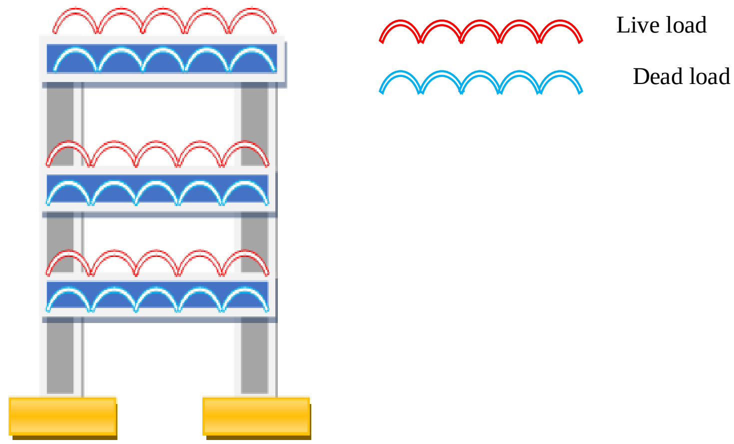

Figure1. Conventional analysis.

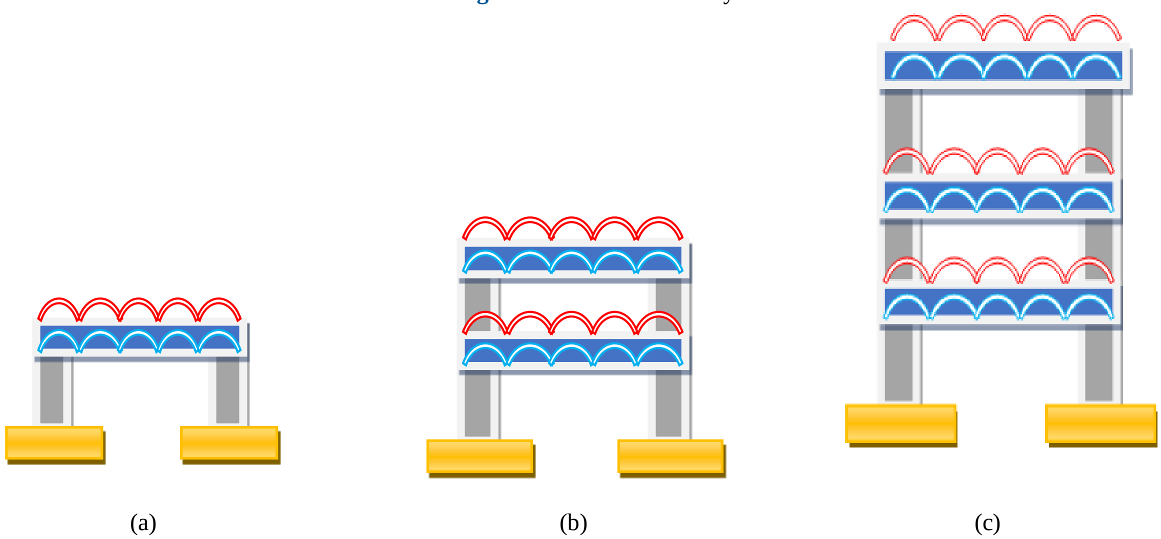

Figure 2. Construction sequence analysis (a) stage 1, (b) stage 2, (c) stage 3.

In the present research, the P-Delta effect was considered along with the CSA. Since the seismic load and wind load effects along with gravity loads behavior were considered therefore it lead to the second-order effects in bending moments and shears. Combinations of CSA with P-delta effect and time-dependent effects were also considered since the construction sequences varied from day one of concreting to stripping time (formwork removal). The loads applied also would vary from the initial stage to the service stage via the construction processing stage. Hence, the inclusion of the time-dependent effect in CSA was closely related to the different construction stages involved during the real-time applications.

The effects of construction sequence were analyzed for a multi-storey building frame and examined that there were considerable variations in the design moments obtained between conventional one-step analysis and construction sequence analysis (Chakrabarti et al., 2019). The effect of CSA along with P-Delta effects had higher values of displacement, shear force and moment in CSA with P-Delta than in the conventional analysis (Viji and Binol, 2017*)*. The CSA was performed on setback steel structure and detected that the bottom storey had suffered the most due to loading due to construction sequence compared to lumped loading analyzed (Nyein and Tin, 2019). The impact of CSA on RC buildings inferred that dead load applied as a sequence produced only minimum additional effects compared to conventional analysis (Nayak et al., 2015*)*. The

Time-Dependent analysis was performed on RC framed structures using construction sequences and found that there were additional column shortening and bending moments when time-dependent effects were included in the construction sequence analysis (Kwak and Kim, 2006). Using CSA for the multi-storey buildings analysis and design has shown accurate results were inferred (Kiran et al. 2017). The long-term effects namely creep and shrinkage in the concrete building using CSA were analyzed and found that CSA time-dependent effects produced the concave-shaped storey displacement plot (Vafai et al., 2009).

Using CSA in multi-storeyed buildings with the designed floating columns by the support of deep beams found significant variations in analytical results namely, axial forces, shear forces, moments and deformations (Pranay et al., 2015). In high-rise buildings, the influence of CSA has caused an increase in the envelope forces, shear force, bending moment and deflection than the conventional method (Santosh et al., 2019). Also in the high-rise buildings, the comparison was made between ASCE 7-16 and IS 1893 (2016) code provisions got similar parametric results. It was reported that the stiffness was highly influenced by the floor plan arrangements (Somil and Muthumani, 2018).

The effect of P-delta analysis in RC framed structures more than 20 storeys could be analyzed and designed, beyond say 30 storeys had increased moments and displacements were noticed (Pattar and Muranal, 2017). The CSA was also applied for long-span cable-stayed bridges where the structural behavior was simulated by the cable stresses and geometric properties that could reduce the errors in real-time scenarios (Michele et al., 2018). For an irregular geometry of setback building, the structural components were analyzed for the response spectrum method with/ without CSA was performed. The functional analysis parameters namely shear forces and bending moments were increased with the CSA approach concerning the storey levels (Vishal et al., 2020). The RC building translations were analyzed using Advanced Staged Analysis Program (ASAP), found to be feasible and beneficial for very high-rise RC buildings (Taehun and Sungho, 2013).

In tall buildings consists of short columns subjected to the shortening effect were analyzed using lumped construction sequences approach. It was inferred that the above approach was much helpful for correcting the errors during the design phase of tall structures (Kim and Shin, 2011). The graph-based comparison was made between the construction sequences adopted in the previous project's case studies with the actual and planned ones. It was reported that this sequential approach to the construction schedule could impart quality construction and enhance the project performance (Ying et al., 2022). Four different methods were compared with the adopted method to validate the performed structural analyses of three structures. It was found that in the proposed method, the correction factor for column shortening and the CSA was adopted (Mohammad et al., 2017). The damage study was performed for the space frame by the modal strain energy method using the FEA tool. It was inferred that the different types of damages could be assessed by the MSE technique (Mathew et al., 2014). Seismic performance was evaluated for industrial structure by a new approach and compared with the limiting values from the code (Turgay et al., 2022).

From the review of literature, it was inferred that very few analysis and design was carried out using CSA and then compared with the conventional analysis & design of the same developed model. In the present analytical research, the CSA was adopted for the conventional/ parent load combinations of dead, live, wind and earthquake loads with the replacement of DL by CSL as sub-combinations as an innovative cum novel approach by carrying out with/ without P-delta and time-dependent effects. The output namely, storeys drift and storeys displacement of worst load combinations was compared with CSA and the conventional method of analysis (parent loads). The critical section was designed for the reinforcement of the beam and column.

In the present research, a 10-storey building frame was considered for analysis and design. Since gravity loads, seismic loads and wind loads were the primary loads considered to configure the load combinations could lead to large axial and lateral displacements. Hence for the above-combined gravity and lateral load effects, P-delta analysis would be preferred. This would lead to an increase in the structural geometrical configurations for fulfilling the transferred load capacity requirements.

2. Methodology materials and methods

2.1 Building plan and drawings

The plot dimensions of the commercial building and their setbacks were planned according to building bye-laws mentioned in NBC (2016) Code provisions. The building plan was placed symmetrically to transfer the applied specific, lateral loads safely to the foundation systems.

The plan of a 10-storey commercial building (hotel) was drafted in AutoCAD software with the area of the building as 25m x 30m as shown(Figure 3). Each storey has an elevation of 4m. The building was assumed to be located at Darjeeling. The type of building used in this study was a setback building having the uniform setback of 10m once after 3 storeys. Also, the building was assumed to be placed at the slope of 10˚ to study the effects of lateral forces.

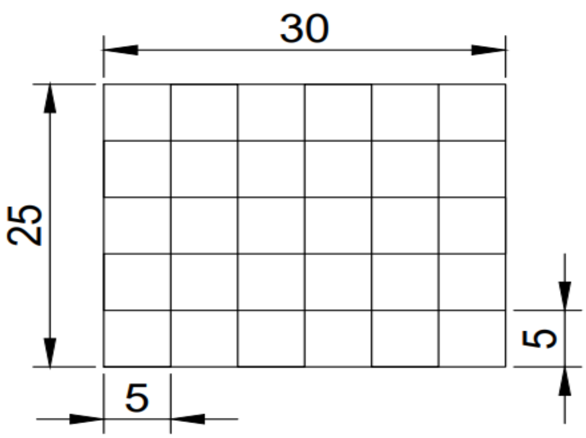

Figure 3. Plan of the Building model
(All dimensions are in 'm')

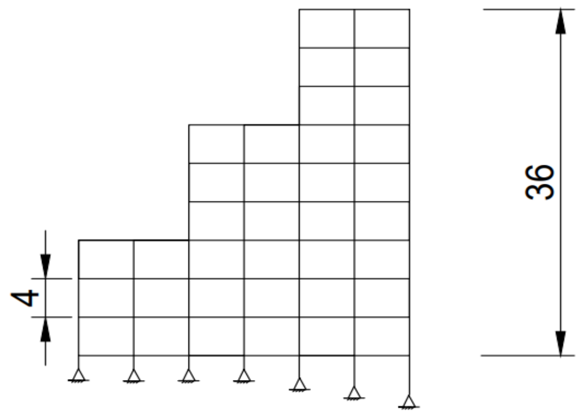

Figure 4. Side view of the building model
(All dimensions are in 'm')

The Columns provided at each junction (Figure 3 and Figure 4) represent the side view of the building model giving a clear view of the setbacks given in the building. It also gives a clear look at different-sized columns placed in the sloped ground. The heights of the columns at the base were 1.4 m for the 1st four columns (from the left side), 2.3 m, 3.2 m and 4 m for the respective other columns. Since the multi-storeyed building is an RC frame, the supports at different positions were provided with fixed supports as completely restrained against translation as well as rotational degrees of freedom. It would ensure the static stability checks were performed based on the support reactions exerted at each node of different foundation level positions. Hence, the plan of the building model was imported to ETABS software and the structural elements of the building model were completely modelled, analyzed and designed. ETABS is the popular software used commercially to perform seismic analysis of RCC Multi-storeyed buildings. Since the simpler generation of 3D model, user-friendly GUI platform and automatic load generations in primary as well as combinations as per the international code provisions adopted.

2.2 Assigning the dimensions and property

After the completion of drawing the framed structure, the material and framed properties had been assigned to the model. As the RCC building was studied here, the material was chosen as M25 Concrete. The Fe 415 grade of steel was selected for main rebars and Fe 250 was provided for confinement reinforcement. The dimension for beams, columns and slabs were defined (Table1). These dimensions are provided to every structural member by using an option called "auto-select" which automatically assigns a dimension to each structural member based on the area required during the design. The dimensions of the structural members assigned initially were shown below.

Table 1. Dimension of structural members.

Structural element	Size
Beams	230mm x 300mm, 300mm x 300mm, 300mm x 450mm
Columns	300mm x 300mm, 300mm x 450mm, 450mm x 450mm
Slab	150mm (thickness)

As the building was placed on a slope and in addition, a type of building was a setback building, it was expected to have a high risk of tackling the lateral forces. So, the four shear wall was provided with each of them facing each direction. The thickness of the shear wall is assumed as 250 mm. The orientation of the shear wall and the full 3-dimensional view of the building are modelled in ETABS (Figure 5).

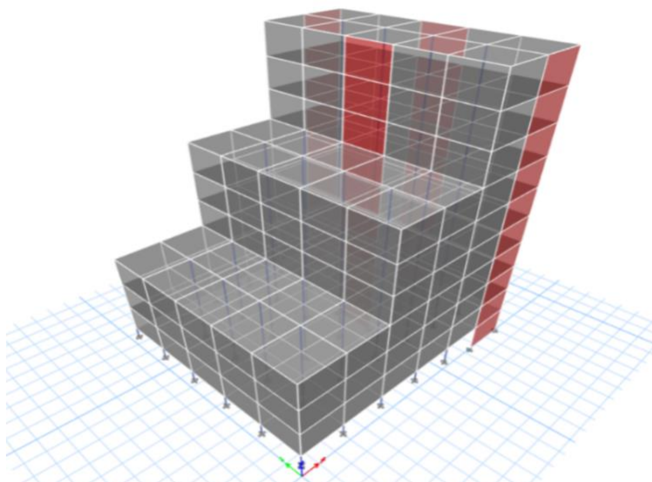

Figure 5. 3D view of the building.

From (Figure 5), it is also inferred that the RC frame configured at the first two stepped levels of the setback buildings is modelled as the ordinary moment resistant frame (OMRF) whereas the third stepped level of the building (elevated than the first & second levels) was configured with the provision of OMRF could resist gravity load & their combinations with symmetrically placed shear walls could resist both wind and earthquake loads & their combinations would act as a ductile concrete frame or special moment-resisting frame (SMRF).

2.3 Application of different types of loads

2.3.1 Gravity loads computation

The gravity loads namely, dead loads (DL) and live Loads (LL) are assigned to the building model. The dead loads on the structure considered include self-weight of the framed structure, loads on the beams due to the erection of walls and the loads on the slabs due to floor finish and other immovable substances. The self-weight of the structure was calculated and assigned automatically by the software which calculates the self-weight of a framed structure with its assigned dimensions and considers the unit weight of concrete as 25kN/m^3. The dead load imposed by brick walls on the horizontal beams are assigned in those beams as UDL. The uniformly distributed load was calculated by considering the unit weight of brick as 15.7 kN/m^3 as per IS 875 Part 1 (1987). Also, the dead load due to floor finish as per IS 875 Part 1 (1987) was assigned to the model. The Live loads on the floors were also assigned according to IS 875 Part 2 (1987). The details on dead load and live load are applied to the building model (Table 2).

Table 2. Dead load and Live load calculations.

Purpose	Height (m)	Thickness (m)	Unit weight of brick (kN/m^3)	Dead load	Live load
Outer wall load	4	0.23	15.7	14.44 kN/m	-
Inner wall load	4	0.115	15.7	7.22 kN/m	-
Slab load	-	-	-	2kN/m^2	4 kN/m^2

2.3.2 Wind load computation

As the height of the building is more than 10m, the wind loads have to be applied as instructed by Indian Standards. Loads applied on the building due to wind forces were calculated and assigned as per the code IS 875 Part 3 (2015). Here we have considered the location as Darjeeling which has a wind speed of 47 m/s. The risk coefficient (k_1) was taken as '1.0' considering that it was a general building structure with a probable design life of 50 years. The terrain category was taken as Category II assuming that terrain was open with well-scattered obstructions having heights between 1.5 m and 10 m. With the terrain category as II and the height of the building as 40 m, the terrain roughness and height factor (k2) were calculated as 1.145.

The Topography factor (k_3) was taken as 1.0 considering the wind slope was less than 3°. The Importance factor (k4) was taken as 1 with consideration of structure as other Structures for the post-cyclone effects. Then the pressure coefficients were calculated as follows: As per IS 875 (Part 3): 2015,Internal Pressure Coefficients = +0.2 or -0.2 [For openings less than 5%]. External Pressure Coefficients: Here, h/w=40/30 = 1.33; l/w = 30/25 = 1.2 where h, w, l are height, least width and highest width of the building respectively. With the calculated ratios of h/w and l/w, the external pressure coefficients as per Table 5 of IS 875(Part 3) -2015. So, a = 0.7; b = -0.25; c = -0.6; d = -0.6 where 'a' represents the windward face coefficient and other represents leeward face coefficients. These resultant pressure coefficients which were the sum of internal and external pressure coefficients were applied to the appropriate face of the building in the ETABS software.

2.3.3 Seismic load computation

The seismic loads were assigned to the building model as per the IS 1893-1 (2016) code. As seen earlier, the building model was considered to be located at Darjeeling which comes under the Seismic Zone IV. The Seismic Zone factor for Zone IV is 0.24. The building was assumed to be placed on Type II soil. The importance factor is 1.2 as it was a commercial building that will be having more than 200 occupants. The reduction factor was taken as 5.0 assuming the building to have Special Moment Resisting Frame (SMRF). The damping ratio as per code was 0.05 for concrete. This seismic load was assigned to the building in both directions i.e., along with and across the slope.

Then, the Mass Source which helps the Software to calculate the Seismic weight of the whole structure was assigned to the software. As per IS 1893 (2016), we will consider 100% dead load along with 25% Live load when the Live load doesn't exceed 3kN/m^2 whereas when the Live Load exceeds 3kN/m^2, then the seismic weight of the structure will be 100% of DL+ 50% of LL. Our dead load consists of self-weight, load due to wall and the loads on the slab. So, we will have 100% of DL. And the live load we considered here was 4kN/m^2 acting on the slabs, so we took 50% of LL for calculation. So, our seismic weight was calculated as 100% of DL + 50% of LL. This information was provided as a mass source to ETABS which in turn used this information in seismic load analysis.

2.3.4 Response spectrum analysis

According to IS: 1893 (2016), the dynamic analysis could be performed by three methods. Among those methods, response spectrum and time-history method of analyses were considered in the present research. As the building taken into consideration was a setback building and placed on a slope, this building model was at high risk during the occasion of any seismic movements caused. Since the building was having vertical irregularities such as stiffness irregularity and vertical geometric irregularity, it becomes necessary to carry out the seismic dynamic analysis. Here, the Response Spectrum Analysis which was one of the methods of dynamic analysis was carried out on the structure.

The parameters used in the static earthquake load calculation were also used here. The dynamic parameters include the parameters governing the design horizontal seismic coefficient (Ah) namely seismic zone factor (Z), importance factor (I), response reduction factor (R) and design acceleration coefficient (Sa/g).With the above-mentioned parameters such as zone factor, importance factor etc. fed to the software, ETABS automatically develops an acceleration spectrum for Zone IV for a given period. Here the software uses a maximum of 12 modes and these 12 modes are used to derive the response spectrum curve for the analysis. The spectrum generated by the software (Figure 6). This spectrum was applied as acceleration to the building and the response was studied.

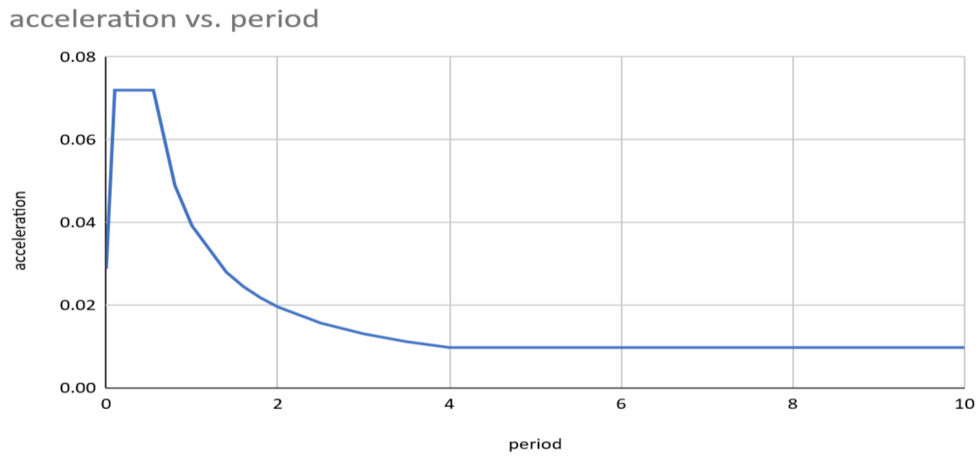

Figure 6. Response spectrum acceleration vs. period curve.

2.3.5 Construction sequential loading (CSL)

For adding the construction sequential loading to the building model, a separate load case was created. As we had three cases of Construction Sequential Loading namely, CSL without P-Delta effects, CSL with P-Delta effects and CSL with P-Delta and Time-dependent effects, a total of three CSL cases were added. In all these three cases, the dead load (DL) was added on a scale factor of 1.0 because the dead loads only are acting while construction. The methods of inclusion of P-Delta and time dependents are discussed below.

2.3.6 Inclusion of P-delta effects

Among the three CSL cases, two cases were having the P-Delta effects namely, CSL with P-Delta and CSL with P-Delta and time-dependent effects. For these two cases, the P-Delta effect with a dead load having a scale factor of 1.0 was added. The other loads were not added as the P-Delta corresponds only to the loads acting during construction.

2.3.7 Inclusion of time-dependent effects

The only case having the time-dependent factors was CSL with P-Delta and time-dependent effects. For the addition of time-dependent factors such as Creep and Shrinkage, the software was fed with information that materials possess time-dependent properties. Then, in the CSL case, the approximate time is taken for completion of each stage of construction i.e., the completion time for construction of 1 storey was added.

It was known that the completion of each stage takes about 7 days. So, in the case of CSL with P-Delta and time-dependent effects, the software was given intimation that completion of each stage takes 7 days. As we have 10 storeys, 10 different stages were considered and each of them was provided with a specific completion time. Also, at each stage, the amount of load added was specified.

2.3.8 Load combinations

For a safe and effective design, it was necessary to carry out analysis and design using the design combinations prescribed by the IS code. The default load combinations were generated by the software itself according to Table 18 of IS 456 (2000) code of practice and IS 1893 (2016) for the failure of the structure by the worst load combinations are as follows: 1.5 (DL+ LL); 1.2 (DL+ IL ± (EL/WL/RS)); 1.5 (DL ± (EL/WL/RS)); 0.9(DL ± (EL/WL/RS)). So, a total of 19 load combinations are generated. Among them, after analysis, 1.5 (DL + EL); 1.5 (DL + WL); 1.2 (DL+ IL + EL); 1.2 (DL+ IL +WL) were found to be predominant in causing more displacements and other effects on the structure. Those effects are discussed in the results.

In the CSA approach, there would be variations between the initial and service stages of loading in the multi-storey building frame. These variations were mainly due to the load applied to the structures Viz. permanent loads, total loads and transient loads. Here the parent load was a specific dead load which was replaced by the construction sequence loads (CSL) in stages and then the structure was analyzed.

As mentioned above, DL in each combination was replaced by 3 cases namely construction sequential loading (CSL) without P-Delta effect, construction sequential loading (CSL) with P-Delta effect and Construction Sequential Loading (CSL) with P-Delta and time-dependent effects. Here only the DL case was replaced and not others because during construction only dead loads (DL) are meant to act on the structure. The live loads will be acting on the structure only after the occupancy of the building. The lateral loads will also be acting at full magnitude only after the complete construction of the building. The combinations in which DL was replaced by CSL cases (Table 3).

Table 3. Combinations of loads used in CSA.

Parent combination	Sub combinations(DL replaced with CSL cases)
1.5 (DL+ EL)	1.5 (CSL without P-delta + EL)
	1.5 (CSL with P-delta + EL)
	1.5 (CSL with P-Delta and time dependent effects + EL)
1.5 (DL+ WL)	1.5 (CSL without P-delta + WL)
	1.5 (CSL with P-delta + WL)
	1.5 (CSL with P-Delta and time dependent effects + WL)
1.2 (DL +LL + EL)	1.2 (CSL without P-delta +LL + EL)
	1.2 (CSL with P-delta +LL+ EL)
	1.2 (CSL with P-Delta and time dependent effects + LL + EL)
1.2 (DL +LL + WL)	1.2 (CSL without P-delta + LL + WL)
	1.2 (CSL with P-delta +LL+ WL)
	1.2 (CSL with P-Delta and time dependent effects +LL+ WL)

The above combinations were added manually in addition to the code prescribed combinations. Then the building model was once again analyzed for the above-mentioned combinations and the results were studied and discussed. With those results, the two of the above combinations which were found to produce the maximum storey drift and storey displacement are studied extensively in comparison to the combination included in the dead load case. It's possible to go with all of the above combinations but it could be a tedious process comparing every combination derived with their parent combinations.

2.4 Analysis and design

First of all, the building was analyzed for the individual load cases such as dead loads, live loads, wind loads, earthquake loads and with response spectrum acceleration generated. These results were interpreted on a first-hand basis so that individual cases that would cause maximum effects can be found and this interpretation could be used in the selection of appropriate combinations. It helped to get the desired results in a shorter time. Then, the building was analyzed for the code prescribed 19 combinations and the four combinations that produced maximum storey responses were selected from the 19 combinations. This process of selection of combinations producing maximum response saves time.

Then, in each combination, DL was replaced with three sequential loading cases as shown (Table 3). Then again the analysis was done and different studies were made by comparison of parent combination with its sub-combinations. The studies include storey displacement, storey drift, internal actions on beams, internal actions on columns and support reactions. After the various studies, the conclusion on using the Sequential loadings in this project was derived. The critical beam and column were also designed according to the Sequential loading case with time-dependent effects.

3. Results and discussion

In this part, the structural analysis and design performed for the modelled frame were discussed in detail. The obtained analytical results namely storey displacement, storey drift, internal action on beams & columns and footing support reactions were compared between CSA and conventional/ parent loads & their combinations adopted in the structural analysis using ETABS software were discussed. The structure is finally designed for the critical section based on the analytical results of worst load combinations predominantly by wind and earthquake loads.

3.1 Storey response for individual load cases

First of all, the building was analyzed with the available load cases such as gravity loads, wind load, and static and dynamic (Response Spectrum Method) seismic loads. The analysis results are studied thoroughly for selecting the appropriate load combinations in which the dead load cases were replaced with Sequential loading. The storey response such as Storey displacement and Storey drift were obtained for the necessary load cases in the direction along the slope (Figure 7 and Figure 8). The storey displacement across the slope was found to be negligible and not considered in this study. Figure 7 indicated that displacement of the storey was recorded maximum due to the earthquake load and wind load with displacements of about 55 mm and 43 mm respectively. The Gravity loads produced very minimal effects accounting for storey displacement of less than 10mm as they are acting in a downward direction. The seismic dynamic analysis carried out with help of Response Spectrum Acceleration also produced minimal effects compared to other lateral load cases. The storey displacement produced by RSA was even lesser than the displacement produced by gravity loads.

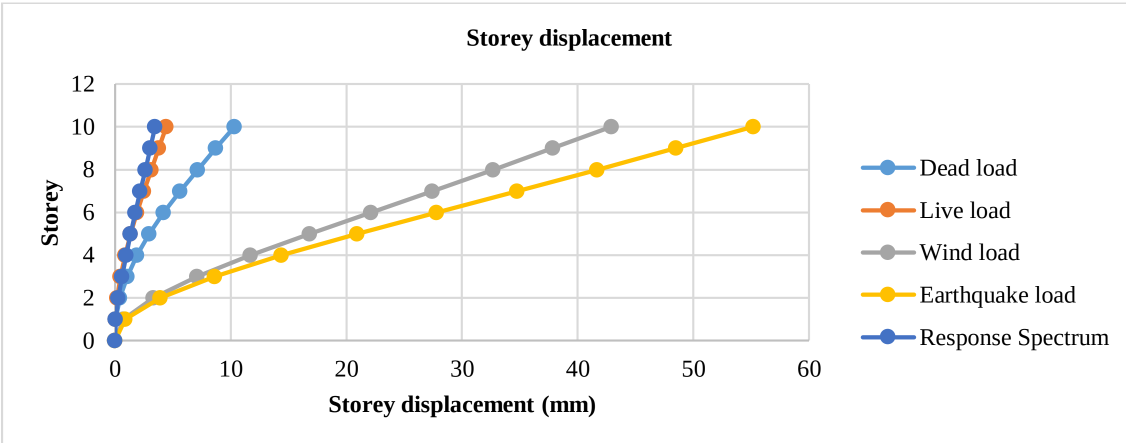

Figure 7. Storey displacement for individual load cases.

The storey drift accounted for individual load cases (Figure 8). The drift was also found to be high in cases of earthquake loads and wind loads compared to others. These plots helped in the observation that the maximum response of the building model was under the lateral loads. The reason for this maximum response was found to be due to the orientation and geometry of the building. This plot helped in the selection of the load combinations that were used in the Construction Sequence Analysis of the model.

With the help of the above plots, the combinations which include the wind load and seismic load with a high factor of safety were selected for the comparison study. Out of 19 code prescribed load combinations, 4 of the load combinations were selected as mentioned in Clause 2.3.6. The storey responses were studied once again with the help of storey response plots obtained for the selected combinations. The storey response plots of the selected load combinations were discussed in the following module.

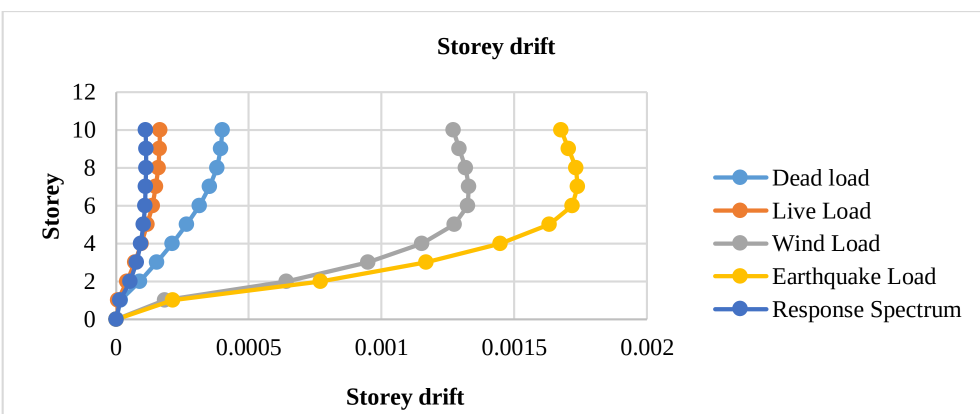

Figure 8. Storey drift for individual load cases.

3.2 Storey response for selected parent load combinations

The static check and equilibrium condition was ensured before undergoing the analysis of parent and CSA load combinations. This was the preliminary check that ensured the stability requirements of the structure subjected to dead and live load with partial safety factors in combinations.

Figure 9 shows the storey displacement recorded by ETABS along the slope for the major four combinations selected. Here, the interpretation was made that the storey displacement was maximum for the combination 1.5(DL + EL/WL). Combination 1.5(DL+EL) produced a displacement of about 63 mm whereas combination 1.5(DL+WL) produced a displacement of about 50 mm. The other two combinations produced the displacement as low as or even lower than individual load cases. This was due to the combined effects of gravity loads and lateral loads which were known to act in different directions. As the dead and live loads are almost the same and the factor of safety of 1.5 applied only to dead loads in addition to lateral loads, the displacement was found to be maximum in comparison to 1.2(DL + LL + EL/WL).

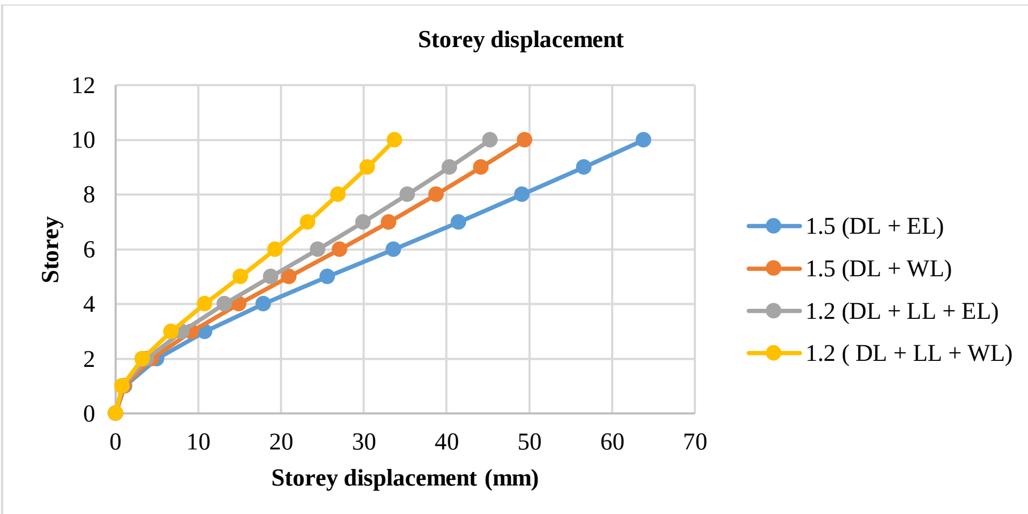

Figure 9. Storey displacement for parent load combinations.

From Figure 9, the partial safety factors adopted for the parent load combination namely 1.5 (DL+EL) have shown the highest storey displacement when compared to the theoretical storey displacement of 0.004 times storey height of 16 mm (limiting value) computed as per IS 1893 (2016). Hence the highest storey displacement has magnified 3.94 times the actual theoretical or limiting displacement since the partial safety factor was considered as 1.5 but should be maintained as 1.0.

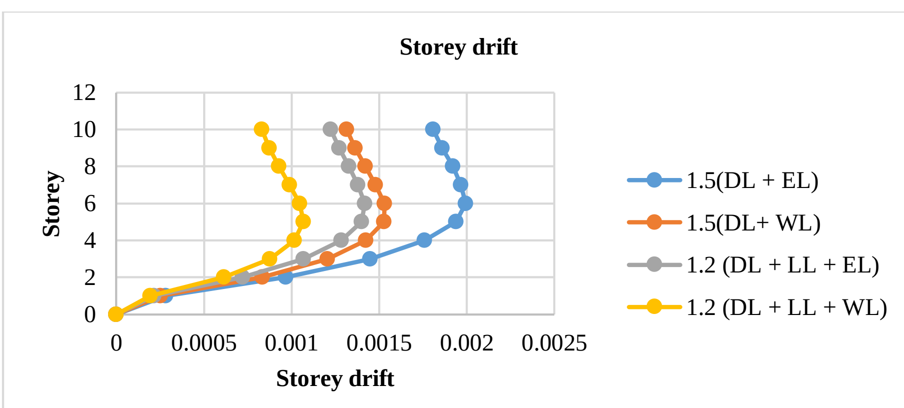

Figure 10. Storey drift for parent load combinations.

From Figure 10 of storey drift, i.e., the measure of displacements between two adjacent storeys is also maximum under the combinations of 1.5(DL+EL) and 1.5(DL+WL). As in the storey drift plot of individual load cases, the maximum drift was recorded in storey 6. The plots were also identical in both cases which represents that lateral loads and load combinations included in lateral loads were producing a similar effect on the structure.

As already discussed in the methodology, the dead load in the selected combinations were replaced with Sequential loading cases with different effects (Table3). But the combinations of 1.5(DL + EL) and 1.5(DL +WL) were found of producing the maximum response from the results of the above studies and hence used predominantly in the following studies made. The other two combinations such as 1.2(DL+LL+EL) and 1.2(DL+LL+WL) were also used in some of the studies.

3.3 Storey displacement comparison between parent and sub load combinations

The analysis results for the displacement of storeys of the model along the slope for combinations of 1.5(DL + EL) and 1.5(DL + WL) and combinations where the dead load was replaced with three cases of Sequential loading in each combination (Figure 11).

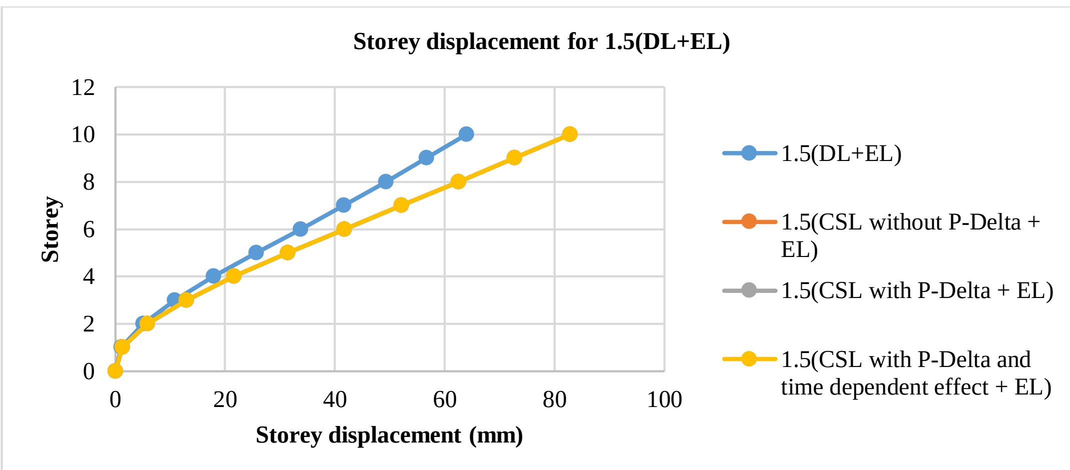

Figure 11. Storey displacement for the factored dead load & earthquake load and its sub-combinations.

As expected from the previous cases of individual load cases, the nature of the plots was the same having the same kind of profile in both plots shown above irrespective of the values of the displacement. Surprisingly, the Sequential loading cases both inclusive and exclusive of the P-Delta effects had shown negligible displacements in both sets of combinations studied. The combination 1.5(DL+EL) and 2 other combinations in which the dead load was replaced with Sequential loading with or without P-Delta effects produced almost similar displacements of the storey but not the same, all along with the height of the building with the maximum displacement of about 63 mm in the top storey as anticipated. Also, the combination in which the dead load was replaced with P-Delta and time-dependent effects produced the maximum displacement in all storeys along with the height of the building, with a maximum displacement of about 82 mm in the top storey.

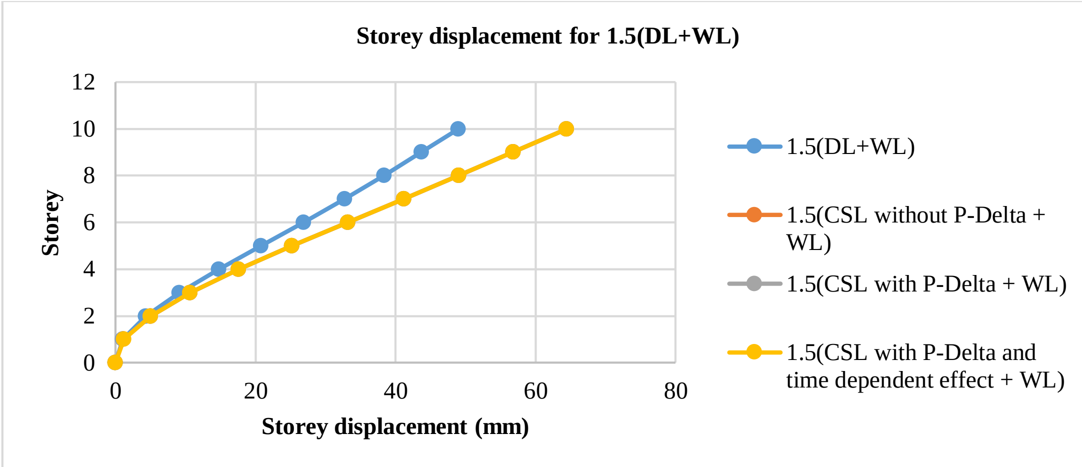

Figure 12. Storey displacement for the factored dead load and wind load and its sub-combinations.

From Figure 12, the combination of 1.5(DL+WL) and the other three cases in which the dead load was replaced with different Sequential load cases produced the same kind of results as in the case of 1.5(DL+EL) but only differing with the values of displacement. Also from Figure 12, the combination 1.5(DL+WL) and 2 other combinations in which the dead load was replaced with Sequential loading with or without P-Delta effects produced almost similar displacements of the storey all along with the height of the building with the maximum displacement of about 45 mm in the top storey whereas the combination in which the dead load replaced with Sequential loading with both P-Delta and time-dependent effects produced a maximum displacement of about 64 mm at the top storey.

From these results, we can interpret that the time-dependent effects such as creep and shrinkage were known to produce the additional displacement in the entire storey along with the height of the building that too during the duration of the construction of the building.

3.4 Storey drift comparison between parent and sub load combinations

The analysis results for the storey drift obtained for the model along the slope for combinations of 1.5(DL + EL) and 1.5(DL + WL) and combinations where the dead load was replaced with three cases of Sequential loading in each combination (Figure 13).

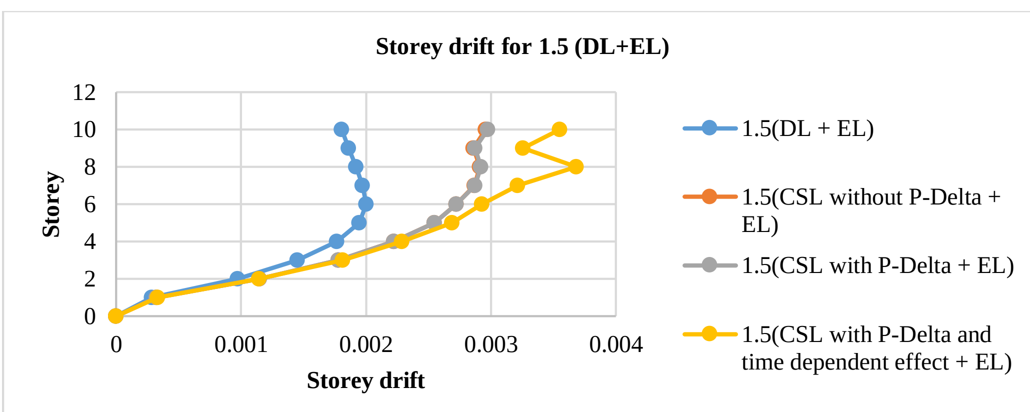

Figure 13. Storey drift for the factored dead load and earthquake load and its sub-combinations.

As seen in the storey displacement plots of two combinations, the profile of the storey drift plots for the same two combinations 1.5(DL+EL) and 1.5(DL+WL) with three other cases for each combination were also similar. As already discussed in the storey displacement plots that there will be a minimum difference in displacement between 1.5(DL+EL) and two combinations in which dead load was replaced by Sequential loading with or without P-Delta effects, here from the plots of the storey drifts obtained for the same combinations, it was evident that there was a minimum difference in storey displacement as we can see that storey drift which was the relative displacement between the adjacent storeys. From Figure 13, the storey drifts for 1.5(DL+EL) were under 0.002 (no unit) for all storeys whereas the storey drifts for combinations 1.5(CSL without P-Delta effects + EL) and 1.5(CSL with P-Delta effects + EL) have a similar storey drift for all storeys but under 0.003 (no unit). It clearly says that there was a difference in storey displacement even though the displacement of all storeys along the height of the building for three combinations was seen as overlapping.

But the combination in which the dead load was replaced with Sequential loading inclusive of both P-Delta and time-dependent effects produced a different profile of storey drift with a maximum drift of about 0.0037 at the 8^{th}storey which was less than 0.004 allowable storey drift value.

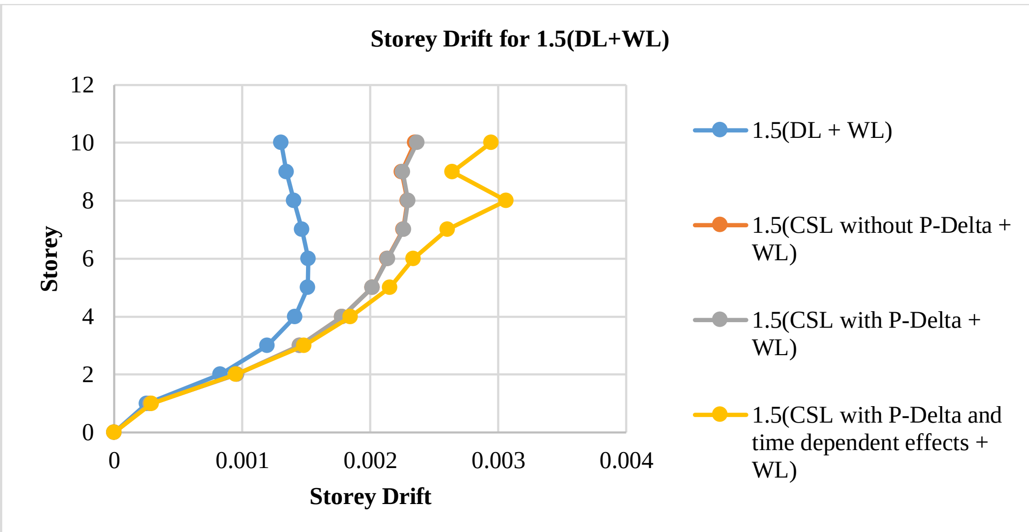

Figure 14. Storey drift for the factored dead load and wind load and its sub-combinations.

As like in the combinations included in earthquake load, the combination 1.5(DL+WL) and two other combinations 1.5(CSL without P-Delta effects + WL) and 1.5(CSL with P-Delta effects + WL) were differing in storey drift where the former's storey drift was under 0.0015 and latter's were under 0.0025 though the profile of storey displacement seemed overlapped proving that storey displacement differs to some extent (Figure 14).Here too, the storey drift was maximum due to the time-dependent effects which produced a maximum drift of 0.00305 in the 8^{th}storey as in the case of earthquake loading combinations was less than 0.004 as per IS 1893 (2016). So it was also evident from the storey drift plots that Sequential loading with time-dependent effects was the one causing utmost effects in comparison to the other cases.

3.5 Internal action on beams

As the effects of combinations in which dead loads were replaced by Sequential loading with P-Delta and time-dependent effects plus the earthquake loads as a whole multiplied by a factor of 1.5 was seen as most predominant in the studies of storey displacement and storey drift, the effects of the beam were studied with only 1.5(CSL with P-Delta and time-dependent effects + EL) in comparison to the combinations 1.5(DL + EL).

The effects on the beams were studied with the help of the ratio of internal actions produced in the beams due to the mentioned combination. The internal actions used here in this study were a maximum deflection and maximum bending moment caused by the combination undertaken. The ratio of internal actions was represented by β for our convenience. The ratio β was given by

$$\beta = \frac{\text{Internal action due to 1.5(CSL with P-Delta and time-dependent effects + EL)}}{\text{Internal action due to 1.5(DL + EL)}} \quad (1)$$

Table 4 shows the ratio of internal action due to 1.5(DL + EL) and 1.5(CSL with P-Delta and time-dependent effects + EL) for the beams placed at the face of the 6^{th} bay of the building in all the 10 storeys throughout the height of the building.

Table 4. Internal action on beams.

Storey	β for maximum deflection	β for maximum BM
1	1.6734	1.9026
2	1.2537	0.9398
3	1.2555	0.9096
4	1.2514	0.8953
5	1.0573	1.0262
6	1.1656	1.1323
7	1.1085	1.0973
8	1.1062	1.0857
9	1.1227	1.2037
10	1.0532	1.1051

With the ratio of internal actions (β), it was clear that the maximum deflection and maximum moments were high due to the Sequential loading case when compared to the conventional load case. The deflection of beams along the 10 storeys produced by the combination "1.5(CSL with P-Delta and time-dependent effects + EL)" was found to be high with an average factor of 1.2048 in comparison to the combination 1.5 (DL + EL). Similarly, the maximum bending moments caused due to the Sequential loading combination were 1.1298 times higher than the maximum bending moment caused due to the combination 1.5(DL+EL).

3.6 Internal action on columns

The effects on the columns were studied with the help of the ratio of internal actions produced in the columns due to the combinations, 1.5(DL+EL) and 1.5(CSL with P-Delta and time-dependent effects + EL). The internal action used here in this study was the maximum bending moment caused by the combination undertaken. The ratio of internal actions was represented by α for our convenience. The ratio α was given by

$$\alpha = \frac{\text{Internal action due to 1.5(CSL with P-Delta and time-dependent effects + EL)}}{\text{Internal action due to 1.5(DL + EL)}} \quad (2)$$

Table 5 shows the ratio of internal action due to 1.5(DL + EL) and 1.5(CSL with P-Delta and time-dependent effects + EL) for the columns placed at the face of the 6^{th} bay of the building in all the 10 storeys throughout the height of the building.

Table 5. Internal action on columns.

Storey	α for maximum BM
1	1.1331
2	1.1539
3	1.0759
4	1.0941
5	1.1027
6	1.0290
7	1.0410
8	1.1881

9	1.2039
10	1.2241

With the ratio of internal actions(α), it was clear that the maximum bending moments were high due to the Sequential loading case when compared to the conventional load case as same as in the beams. The maximum bending moment of columns along the 10 storeys produced by combination "1.5(CSL with P-Delta and time-dependent effects + EL)" was found to be the maximum bending moment which was 1.1246 times higher than the maximum bending moment caused due to the combination 1.5(DL+EL).

From the ratios of internal actions obtained for both beams and columns studied throughout the height of the building for a single bay, we conclude that maximum effects were caused due to the Sequential loading considering both P-Delta and time-dependent effects when compared to the combination 1.5(DL+EL). So, if we can plan and design a building according to the sequential loading inclusive of both P-Delta and Time-dependent effects, the life of the structure can be increased to some extent.

3.7 Footing support reactions

From the study of footing support reactions, the loading cases and combinations which produce the maximum loads that ought to be transferred to the support can be known, which might help in obtaining the combination best suited for the design. It was known that 1.5(DL+EL) was transferring the maximum load under conventional cases. Here, as like in the previous studies, the sequential load combination, 1.5(CSL with P-Delta and time-dependent effects + EL) was compared with 1.5(DL+EL) for the 10 supports known to have maximum reactions (Table 6).

Table 6. Support reactions.

1.5(DL+EL)		1.5(CSL with P-Delta and time-dependent effects + EL)	
Fz (kN)	Mx (kN-m)	Fz (kN)	Mx (kN-m)
7398.324	272.2918	12141.36	282.7824
7135.896	447.7368	10630.94	443.3757
4636.314	272.7319	9379.353	265.26
5786.662	13.6781	8124.262	-34.2473
5786.662	53.6704	8124.262	126.5092
4396.192	458.8832	7891.234	467.6905
4090.572	53.8372	7159.083	140.8809
2501.681	10.0279	5570.192	-49.6532
2300.591	36.3488	4868.491	37.574
2118.518	33.7221	4686.417	34.2941

From the above results for both the combinations, it was found that the reaction at the support caused by an axial force acting downward from the columns to support is very high due to the sequential load combination in comparison with the conventional combination. They both differ by a factor of about 1.8 which was very high and indicates the importance of sequential loading combinations. But the moments caused at the supports due to both the combinations do not vary too much.

3.8 Design of critical members with sequential loading combination

After successful analysis with Combinations including various cases of Construction Sequential loadings, the design of critical beams and columns was carried out by the ETABS software with the same sets of combinations. The details of the beam and column design are discussed below in brief.

The beam (300mm x 450mm) of length 5 m at the 8th storey was found to be a critical beam with a maximum bending moment of 540.3841 kN-m at one end of the beam. The maximum shear force experienced by the beam was 334.6241 kN at

4.775 m. The maximum BM and SF were found to be caused due to the combination of 1.5(CSL with P-Delta and Time-dependent effects + EL). It was designed with a main reinforcement area of 2359 mm^2 and a transverse reinforcement area of 3566 mm^2 per meter of the beam.

The Column (450mm x 450mm) of the height of 4m at the base was found to be critical with the maximum axial force acting on the column as 7922 kN. The Column was designed by the software for the combination 1.5(CSL with P-Delta and Time-dependent effects + EL) which caused the maximum axial force on the column. The Column was designed with the main reinforcement area of 6940 mm^2 and a shear reinforcement of 498.8 mm^2 per meter of the column.

4. Conclusions and comments

In the present research paper, a novel attempt was made to analyse and design the RC building frame by checking against BIS code provisions for a 10-storey setback commercial building placed on the slope Viz. Conventional, CSA- with/ without P-delta and time-dependent effects in individual & combinations of gravity and lateral loads analyses were examined for the output parameters namely storey drift, storey displacements, bending moments and shear forces obtained for the structural components using ETABS software are discussed below:

1. Based on the results, the Construction Sequence Analysis was found to be more predominant than the Conventional one-step analysis in causing the different effects on the structure. The loads due to Construction Sequence during construction were proved to cause some more effects on the structural members in addition to the loads applied to the structure;
2. The Construction Sequential Loadings with P-Delta and time-dependent effects were proved to have the most effects on structure compared to the other two cases of Sequential loadings. The effect of the additional moment due to the P-Delta effect seems to be negligible and the response due to Construction Sequence Analysis with and without the P-Delta effect was almost similar;
3. Though CSL with P-Delta and time-dependent effects were predominant, the reason for this predominance was only the time-dependent effects because the study also revealed that CSL with and without P-Delta had produced only similar effects;
4. The maximum storey displacement and drift caused by combinations included of CSL with time-dependent effects were almost twice that of the same obtained for the building analysed with parent load combinations;
5. The internal actions of beams and columns such as displacement, bending moments and axial forces were also found to be high for CSL combinations compared to their parent combination;
6. The time-dependent effects such as creep and shrinkage were known to produce additional displacement in all the storey along with the height of the building that too during the construction of the building;
7. The storey drift produced by CSL with time-dependent effects case was approximately 28% more than that of CSL with P-Delta effects and 80% more than that of its parent case. The storey displacement produced by CSL with time-dependent effects case was approximately 30% more than that of its parent case;
8. The deflection on beams due to (CSL+ time effects) case was 1.2 times higher than normal analysis whereas the BM on beams due to (CSL+ time effects) case was 1.1 times higher than normal analysis;
9. The BM on columns due to (CSL+ time effects) was 1.1 times higher than conventional analysis;
10. The effect of time-dependent factors such as creep and shrinkage seemed to be high in the sections at the bottom storeys.

Author contributions: G.C.Balaji: Planning, Modelling, Analysis & Design of RC multi-storey commercial building using ETABS software; S.S.Vivek: Checked the model, analysis & design Output results, writing the research paper.

Funding: There is no funding.

Acknowledgements: The authors would like to thank the Vice-Chancellor of SASTRA Deemed University for the lab facilities provided for carrying out this research work.

Conflicts of interest: The authors declare no conflicts of interest.

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