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Strong Column-Weak Beam Concept and Stiffness Factor Study for Moment Ressisting Frames

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Abstract:- One of the biggest challenge for structural engineers is to design a safety structure that is going to resist during seismic activities, therefore the concept of strong column and weak-beam. To withstand those loading that sometimes tend to overpass the elastic limit and lead to the collapse mechanism, it is crucial to perform the pushover analysis that is a non-linear static analysis where the structure is subjected to lateral stresses. As a result, various characteristics are recorded, including failure, the development of plastic hinges, and yield. Since the columns are the components from which all the loads are transferred to the foundation, having more rigid columns rather than beams is important in the formation of plastic hinges. The elastic stiffness factor measures how well a structure can withstand stresses before failing and having plastic hinges. The aim of this paper is to make a contrast on the zone of plastic hinges formation with respect of the concept of strong column and weak-beams but also the assessment of the stiffness factor. In order to fulfil the purpose of this study using ETABS software, pushover analysis has been performed on 12 two-dimensional reinforced concrete and steel frames with variation of span length and number of span. The pushover analysis gave the hinges formation zone and the stiffness factor has been evaluated using the pushover curve. The study shown that, the distribution of the plastic hinges and stiffness are affected by the span length, the number of span but also the material because reinforced concrete frames are found to be safer and stiffer than steel frames. The stiffness is found for the Reinforced concrete to decrease with around 50% and 40% of decrease is observed for steel frames.

Keywords:- *Strong Column Weak-Beam (SCWB), Reinforced Concrete (RC), Collapse Mechanism, Pushover Analysis and Stiffness Factor.*

I. INTRODUCTION

The SCWB consideration in the code aims to lessen the chance of storey mechanism formation in the structure. Beams plastic hinges are the ideal and adequate energy dissipating manner for the structure to remain safe in seismic condition because whenever the collapse happens in the beams, the collapse is partial but when it takes place in the columns, the whole structure might collapse what is called global failure. The failure modes in most of the previous earthquakes has shown that strong beam weak column is a key issue that causes columns to sway, therefore leaded to the collapse of the structure. The structure must have required capabilities to withstand earthquake forces in order to be prevented from sudden collapse (Buyukkaragoz & Arslan, 2014). According to the ACI 318 requirements, the column-to-bream strength concept must be at least 1.2 when added together at the joints. Strong column-weak beam refers to the requirement that the node at the column end and beam real flexural capacities should meet this: Mc> Mb. Many loads and combinations should be considered while constructing a structure, including lateral loads like wind and earthquake that might cause significant human casualties. When they occur, lateral loads are among the riskiest events, thus structures must be specially designed to withstand them. The lateral stresses cause the structure to bend, where the base shear increases until it reaches its maximum with a rise in lateral displacement till collapse (Ahmad, 2021). Hinge refers to the inability to withstand a moment. A plastic hinge functions like a regular hinge would, allowing for unrestricted rotation. Grasp structural failure requires an understanding of the plastic hinge idea. The stiffness factor is function of the first hinge that appeared on the pushover curve.

II. METHODOLOGY

This section deals with the details about the process followed to fulfil the study of SCWB but also the stiffness by modelling six RC and six Steel frames and analyzed by using the nonlinear static method that is the pushover analysis by the mean of ETABS software. After performing the pushover analysis, the plastic hinges zone has been assessing in first hand but also the stiffness factor in the other hand in order to figure out the deformation. This section's key topics include material characteristics, simulated frames, loads applied, pushover analysis, collapse mechanism and stiffness.

➢ *Material Properties*

The material used for this study are concrete and steel for modeling the 2D frames. The primary materials employed in this study are steel grade A992Fy50, which represents the steel frames material and concrete grade C25, which is used for RC frames. The wild flange section (W-section), according to the 13th edition of the AISC Steel Construction Manual was utilized for steel design and ACI was the reference for the concrete frame design. The characteristics of the materials utilized in the models for this investigation are summarized in Table 1.

Table 1 Material Properties

Material properties	Concrete (C25) MPa	Steel(S50) MPa
f_u	-	448.16
f_y	-	334.74
f'_c	25	-
E	23500	199947.98

➢ *Geometry of Frames*

A total number of 12 frames in 2D with a column-beam ration of 1.2 have been modeled and analyzed. All frames have the same section and same story height for same a material but the length and number of the span are the elements played on to assess the hinge formation and the variation of the stiffness.

Table 2 Frames Details

	Concrete	Steel
Beam	400×800	W14×26
Column	200×400	W12×106
Storey height	3m	3m
Number of storey	10	10
Number of span	3 and 5	3 and 5
Span length	5.5m, 6.5m, 7.5m	5.5m, 6.5m ,7.5m

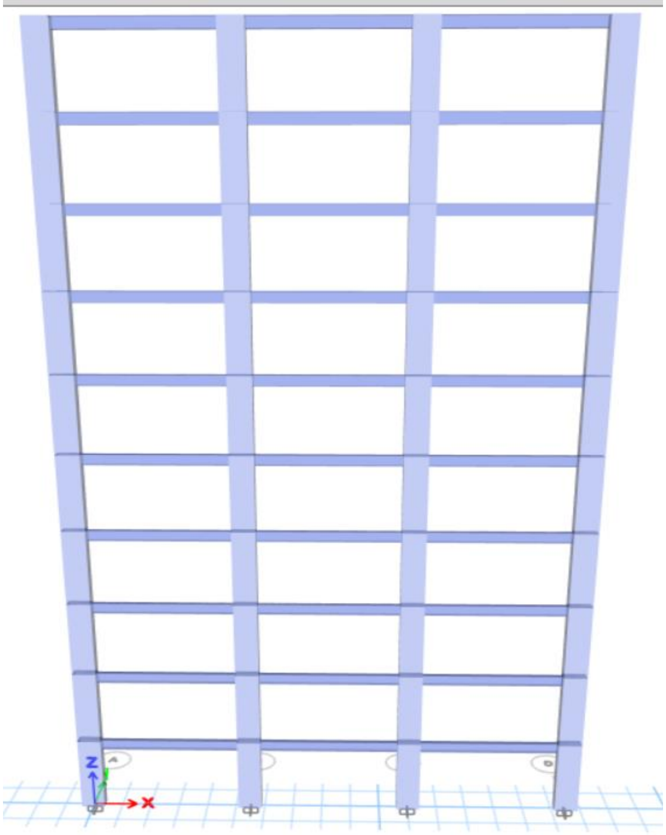

Fig 1 Elevation of the 2D frame

➢ *Loads Applied*

For the sake of similarity, similar loads have been applied to the RC and steel frames what are dead load, live load, super dead load and lateral load. The program compute the dead load automatically; the live, super dead and lateral loads are 25 kN/m, 15 kN/m and 100 kN, respectively.

➢ *Pushover Analysis*

Pushover, as its term suggests, refers to the act of forcing a structure to the limit of its flexibility (Alhassan & Abdelrahim., 2020). The two forms of pushover analysis are capacity spectrum and displacement coefficient approaches. Pushover analysis is a static method for calculating seismic structure deformations using a streamlined nonlinear method. When there is an earthquake, buildings remodel themselves. After performing the analysis, the plastic hinges are formatted along the members and the pushover curve is also obtained. Since the curve is function of displacement and load P to be applied to the frame's top storey, there is 3 methods:

- The Approach Of Quasi-Static.
- Simply Indicate The Whole Load.
- Provide The Displacement, And The Program Will Automatically Apply The Load Based On It For This Study, The Last One Is Used.

➢ *Collapse Mechanism*

The members of a structure primarily maintain their elasticity until when pushover loads are applied up to a particular moment Mp, which corresponds to the maximum moment of resistance of a fully yielding section. The element will rotate with little increase in load if the moment is increased sufficiently and that rotation happens at that specific moment Mp (Ali Irfani & Vimala, 2019). Plastic hinges are the predicted zone of damage brought on by surrendered zones with significant inelastic rotation aptitudes at constant restraining moments Mp. After the analysis done, the plastic hinges have different color and the meanings are as described in the following: green dots denote the beginning of yielding (BC), blue colors the ultimate strength (CD), pink colors the residual strength (DE), and red colors the maximal production of residual strength (after E) (Yadav and al., 2017) The collapse mechanism is the combination of inelastic hinges at the ends of beams and columns that, when created in a building, ultimately causes one to become unstable and collapse. The displacement coefficient method is the chosen for this study and the location of hinges on each members is 10% and 90%.

➢ *Stiffness Factor*

The building's capacity to absorb applied stresses without developing plastic hinges is measured by the elastic stiffness factor K (Sarhan & Raslan., 2020). The overall measurement of the amount of deflection brought on by the load on the material is known as stiffness. After performing the pushover analysis according to the pushover curve, the stiffness factor of each frame structure has been determine since the formula is given as the ratio of the base shear over the displacement taking at the first plastic hinge.

$K = \frac{V_S}{D_S}$ With K= Elastic stiffness in kN/mm, V_S= Base shear at the first plastic hinge and D_S= Displacement at the first plastic hinge.

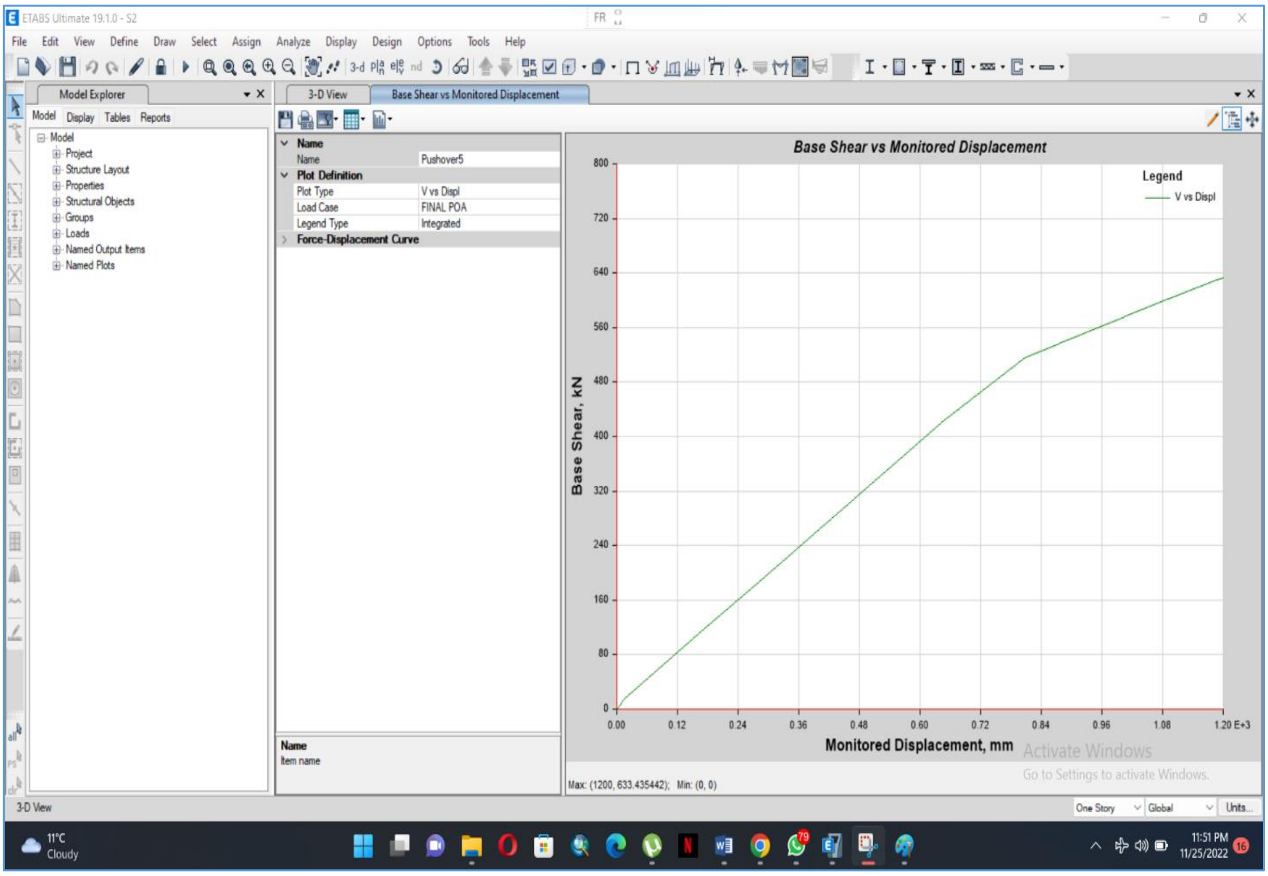

Fig 2 Pushover Curve for Steel Frame

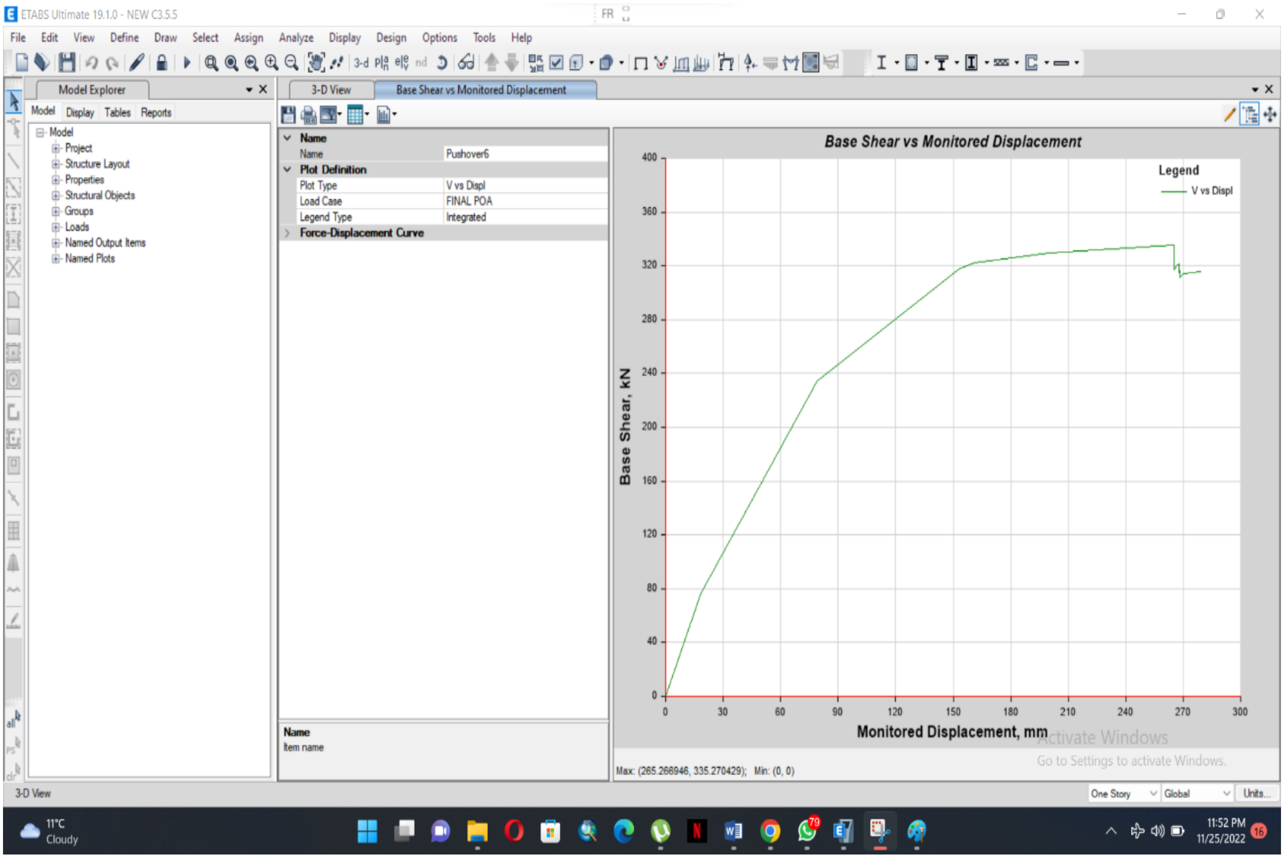

Fig 3 Pushover Curve for RC Frame

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III. RESULTS AND DISCUSSIONS

In the attempt of analyzing the SCWB concept, results and analyses of 2D frames that were examined based on the study, as described in earlier parts, are presented in this section. These findings primarily evaluate plastic hinges zone in terms of location and also in terms of elastic stiffness. The span lengths, the number of span and are the variables taken into account in this study. The results regarding the development of plastic hinges and the results regarding the values of the pushover curve are the two main sections of the results and discussions section. They are as described in the graphics that follow.

➢ *Collapse Mechanism*

- *RC Frames*

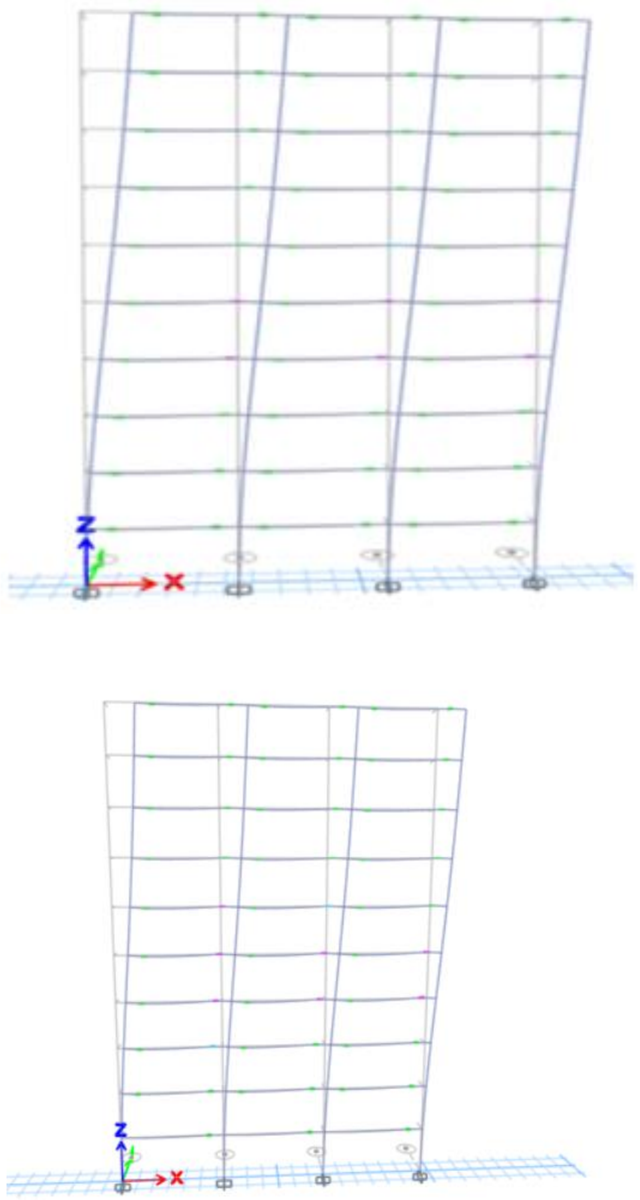

Fig 4 Collapse Mechanism of 3 Span with 5.5m and 6.5 Span Length RC Frame

The behavior of a ten story building's collapse mechanism is depicted in Fig. 4 for different length but gave similar result with a strong column weak beam value of 1.2.The plastic hinges originally emerged in the beams only with some critical points at storey some storey. The hinges are observed to be well distributed from the first till the last storey, even with some changes in hinges color the result is still in the range desire behavior because the rotation did not reach the yield. The critical zones are located at the 4 and 5 storey where the hinges color has changed. Therefore, it can be said that the strong column weak beam idea of 1.2 as it is presently expressed in codes incorporates beam collapse mechanism that distributes damage across the structure.

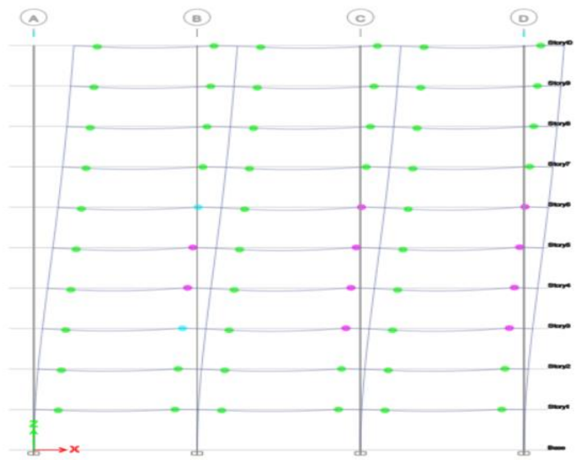

Fig 5 Collapse Mechanism of 3 Span with 7.5m Span Length

Figure 5 shows the collapse mechanism of 7.5m span length and the location of the plastic hinges indicate a distribution to the top of the storey even though there is critical hinges in 3, 4, 5 and 6 storey what implied a rotation therefore a collapse of beam. With the considerable increment in length, the structure seems to be more reactive to hinge color changes but still did not reach the critical yield what is the red hinge color. It can be say that the SCWB ratio of 1.2 concept as indicate by the code is enough to form beam collapse only.

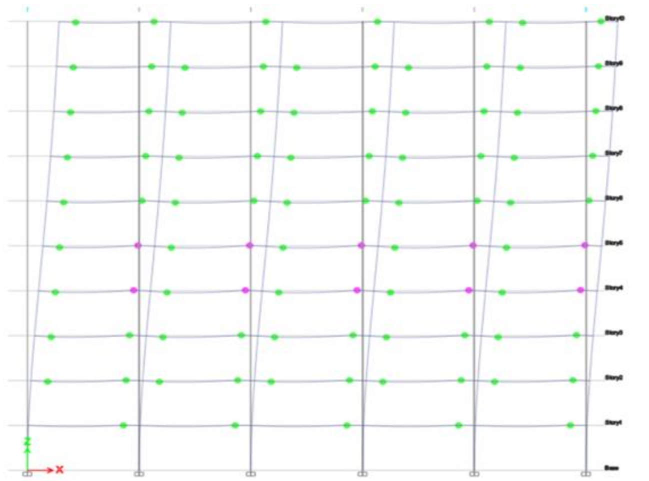

Fig 6 Collapse Mechanism for 5 Span with 5.5m and 6.5m

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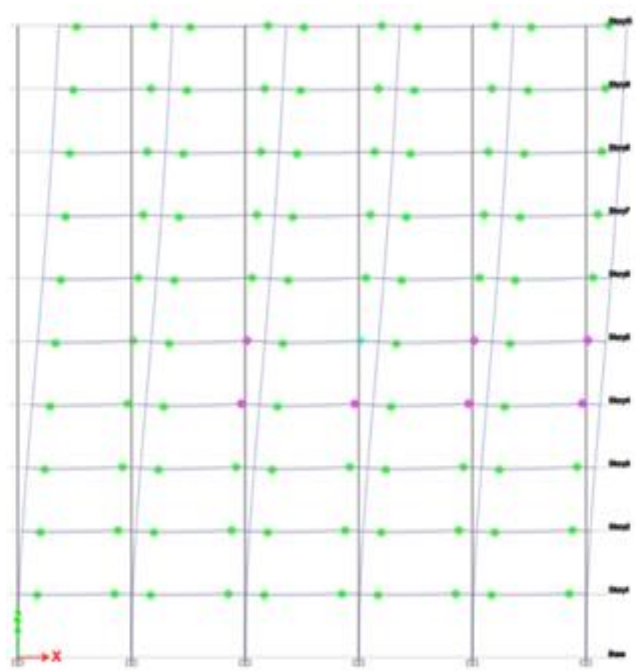
Figure 6 shed light on the hinges formation and distribution in the collapse mechanism of 5 span frame where the critical hinges are formed in the 4 storey for both frame even with the increase of the length but with a perfect distribution to the top of the storey. That made the SCWB concept verified because it is formed only beam collapse zone with the ratio given by the code.



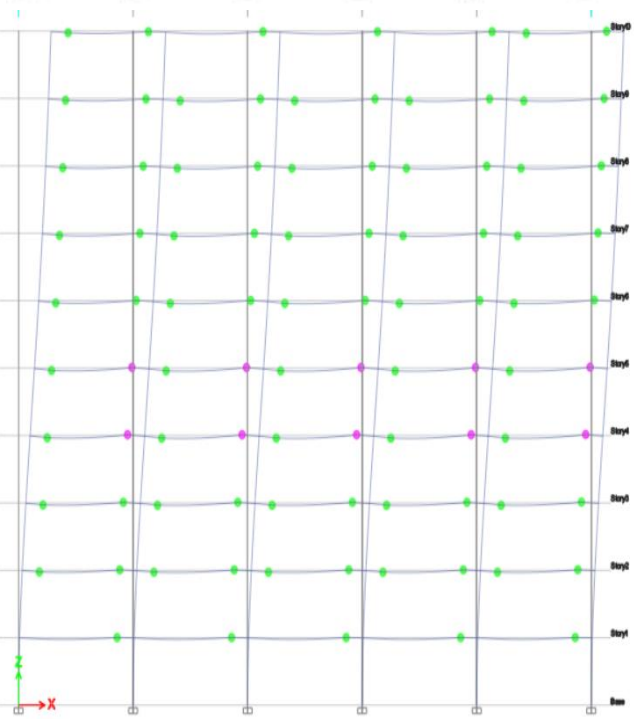


Fig 7 Collapse Mechanism of 5 Span with 7.5m

The collapse mechanism is also verified in the figure 7 as the hinges are in pink color and the hinges are distributed from the bottom to the top of the storey as desired in order for the energy to be dissipated uniformly. The SCWB concept is therefore verified also for this case.

- *Steel Frames*

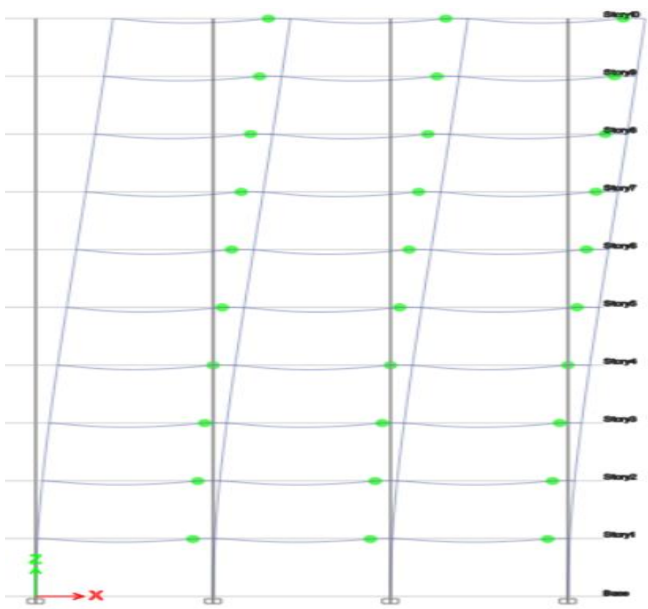


Fig 8 Collapse Mechanism of 3 Span with 5.5m

As for the 5.5m length frame, there is a partial distribution of the plastic hinges located in some zones of the beams only from the first to the last storey. The collapse here also is happening in the beams as required by the code but with improper distribution of the hinge for the design of SCWB. It can also be considered as good.

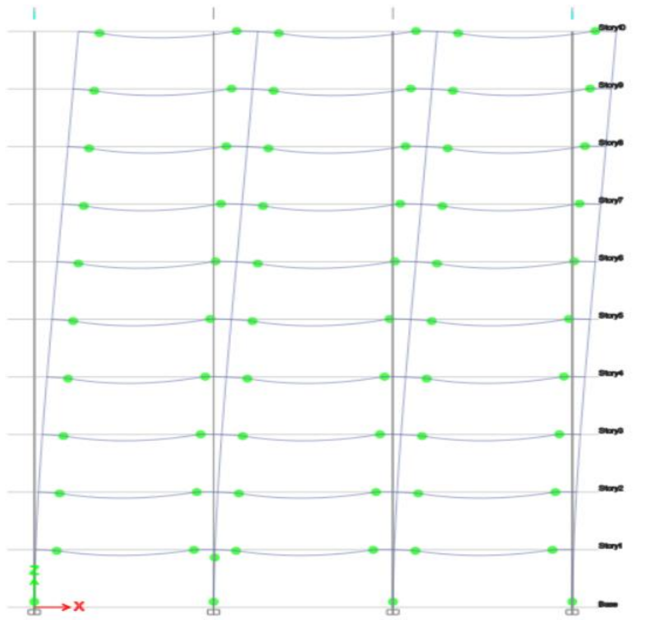


Fig 9 Collapse Mechanism of 3 Span with 6.5m

Figure 9 illustrated the hinges formation and it is observed that the plastic hinges are formed in the base of the all columns despite the good distribution from the top to the bottom. But the formation of plastic hinges at the base make the structure unstable because the collapse in this concept must take place only in the beam in order to minimize the effect. Therefore it can be conclude that the structure is not safe.

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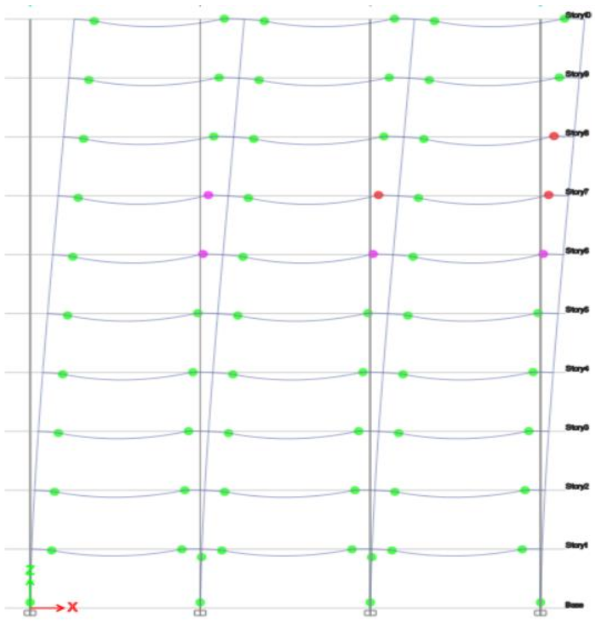


Fig 10 Collapse Mechanism of 3 Span with 7.5m

The hinges are formed in figure 10 at the base of the columns as well as the red hinges formation at the storey 6, 7 and 8 what show a great unsafety of the structure because of the yield in red and the base hinges. The structure is unsafe because the energy cannot be distributed from the first storey till the last storey.

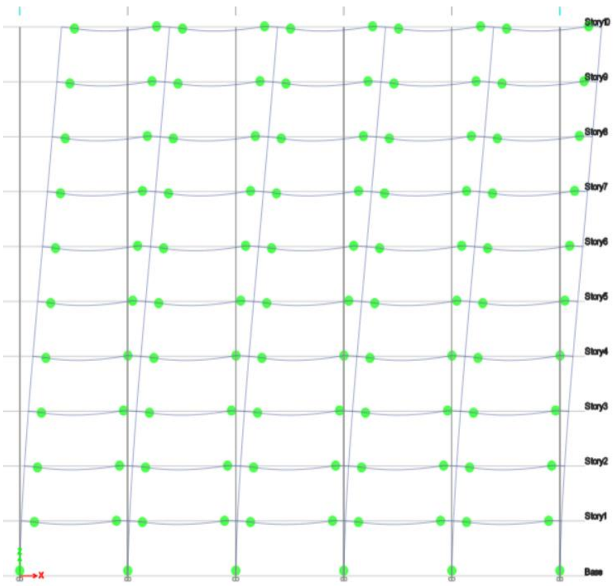


Fig 11 Collapse Mechanism of 5 Span Steel Frame with 6.5 M Length

In the behavior of the collapse mechanism, the plastic hinges primarily emerge in the columns well before beams making it a weak columns thing that is going to lead to global collapse. The strong column weak beam idea as it is defined in codes, therefore, incorporates a column collapse mechanism that disperses damage across the structure. The development of plastic hinges in the column affect the immediate tenant and will cause the building to collapse. Same analysis has been observed on the frame with 5.5m.

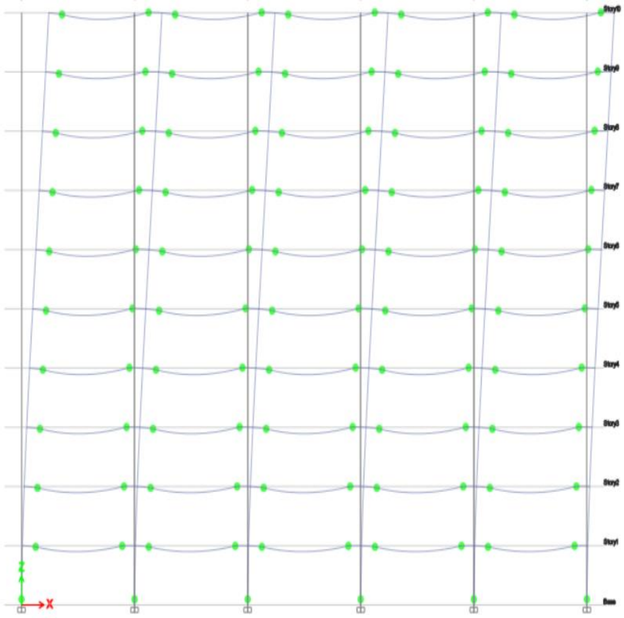


Fig 12 Collapse Mechanism of Steel Frame of 7.5m Length with 5 Span

There is same analysis for all the steel frames with 5.5m and 6.5m where a clear distribution of the hinges from the first storey to the top. The collapse mechanism is taking place in the beam as required for the in the design of SCWB but the appearance of hinges in the base column is involving a global collapse. So basically, the structure is not safe.

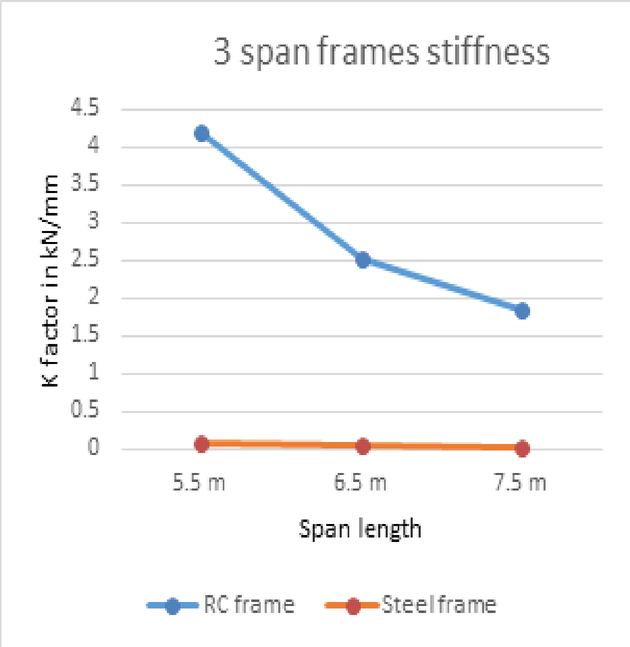
For the RC frames, the hinges zone indicate that with the increase of the length of the span or the number of spans, the structures reveled some changes of hinges color in some point turned to pink color without reaching the yield point that is the red hinges color. It is observed also that there is not hinges formation for the all 6 frames analyzed at the base of the columns what confirm as well the desired behavior for dissipating the energy. In the other hand, the steel frames shown an opposite behavior for all the fames analyzed, with the increase of the length and span the result remains almost same by showing an unstable behavior that can lead to the collapse. According to the collapse mechanism of the RC and steel frames, it is obvious that the RC structure is responding better than steel structure to the collapse mechanism of SCWB concept because it is shown that the material provided a better safety with a proper distribution of hinges to the top of the storey.

- *Stiffness Factor*

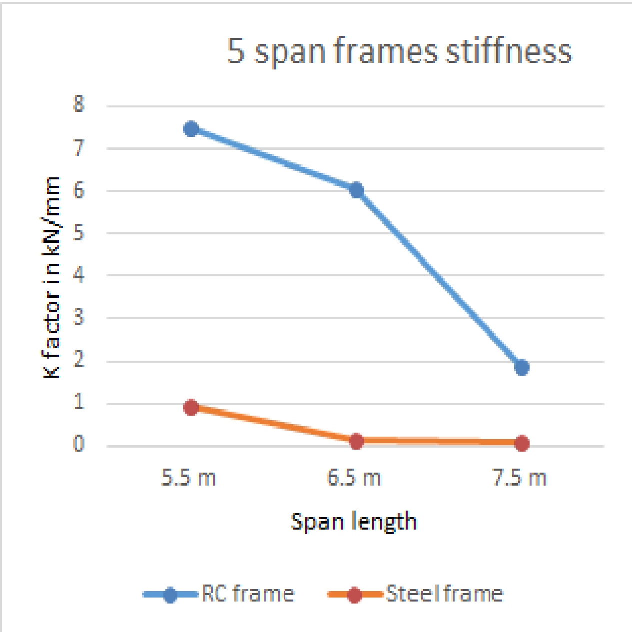
Table 3 K factor for the Frames

Span length	RC frame	Steel frame
3-5.5 m	4.21 kN/mm	0.09 kN/mm
3-6.5 m	2.53 kN/mm	0.06 kN/mm
3-7.5 m	1.86 kN/mm	0.036 kN/mm
5-5.5 m	7.48 kN/mm	0.95 kN/mm
5-6.5 m	6.05 kN/mm	0.13 kN/mm
5-7.5 m	3.57 kN/mm	0.1 kN/mm

➢ *Length and Number of Span Effect on Stiffness Factor*



Graph 1: 3 Span Frames Stiffness Factor

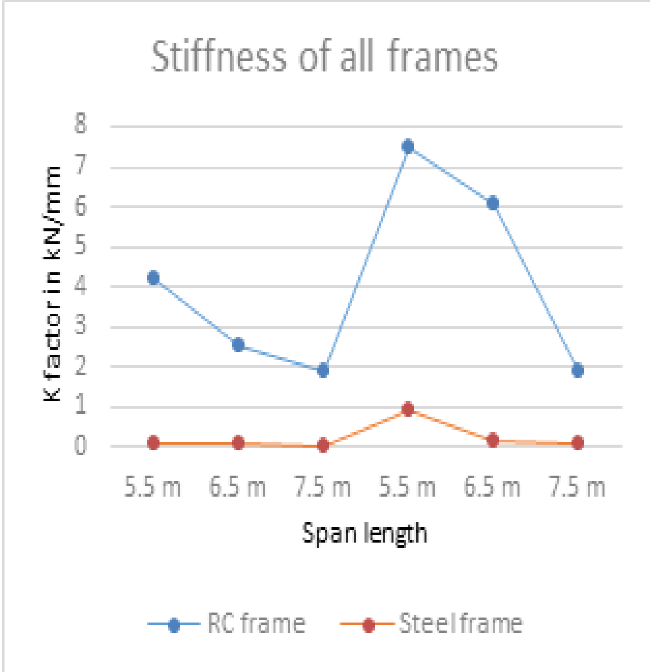


Graph 2 : 5 Span Frames Stiffness Factor

The span length is a factor that greatly impacts on the elastic stiffness. It was discovered that when span length grows up, the elastic stiffness goes down. This is due to the columns because they are closer in a smaller span while fare in a greater span, therefore there will be a decreased of the stiffness. The increase in number of span from 3 to 5 has an effect on the stiffness as well because it is found that the K factor increased considerably.

The influence of span length and number of span on the stiffness of moment-resisting frames is illustrated in the graphs of figure 14 and 15 but also in the table 3.

➢ *Material Effect on the Stiffness*



Graph 3 : Stiffness of all Frames

According to the finding of the graph 3, it is clear that the RC frames K factor is much greater that for the RC frames. This is due to the fact that members with larger cross section are always stiffer than the one with a smaller cross section.

IV. CONCLUSION

➢ *After the Pushover Analysis Performed on the 12 Moment Resisting Frames, it is Found that:*

- The plastic hinges formation of RC frames provide a full safety of the structure in contrast implied only beam collapse for all the frames which means that in case of collapse only beams will be affected which is a partial damage and this result is the desired behavior.
- In contrast, the steel frames has shown an improper distribution of plastic hinge for the frame with 5.5 m as span length and for the others, it appears some hinges at the base of the columns which is going to cause a rotation on the columns, therefore will lead to a global collapse.
- It has been therefore, according to the finding that the RC structure with the chosen section provide a better result in terms of collapse behavior rather than the steel frames.
- Regarding to the stiffness factor, it is found that as the span length increase, the stiffness decrease; and with the increase in number of span, K factor increase. The stiffness is found to be decreasing with around 50% for the RC frames and 40% for steel frames.
- It is observed also that, the stiffness of RC structure is much greater than steel structure, therefore the RC frames are stiffer than steel frames.

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