International Journal of Current Engineering and Technology

E-ISSN 2277 – 4106, P-ISSN 2347 – 5161
Available at http://inpressco.com/category/ijcet

National Conference on Recent Advances in Civil Engineering Infrastructure (rACEi-2021)

A Review on Comparative Pushover Analysis on Different Frame Structures

Raghuvaran Komati and Battu Jaya Uma Shanker

Research Scholar, Assistant Professor Department of Civil Engineering, CMR Institute of Technology, Hyderabad-501401

Received 05 Aug 2021, Accepted 10 Aug 2021, Available online 15 Aug June 2021, **Special Issue-9 (Aug 2021)**

Abstract

Due to rapid growth of population, construction of high-rise buildings became predominant. Those buildings which are not designed against seismic excitation leads to heavy structural damage due to vibrations generated by earthquake at the ground level. For low-rise buildings, reinforced concrete structures are being used over many years due to their flexibility and cost-effectiveness. Reinforced concrete structures are no longer preferred for medium to high-rise buildings due to their heavy load, lesser stiffness and hazardous formwork. Steel and composite frames are preferred for high-rise structures due to their higher flexibility and lighter weight. Composite frames are mostly preferred which enhances the stability and life of structures. Pushover analysis is a static non-linear approach which analyses the successive damage of the structure using ETABS. In this study, review of pushover analysis of different frames used for high-rise buildings such as RCC, steel and composite frames are to be discussed. Base Shear, lateral displacement of structure, time taken by structure to oscillate due to earthquake shaking and response of structure due to variation of number of stores are to be analysed. It is concluded that the steel and steel-concrete (composite) structure are the safe choice for constructing high-rise buildings due to flexibility, ductility than reinforced concrete structures.

Keywords: *Composite, High-rise buildings, Pushover analysis, RCC, steel*

1. Introduction

Earthquake is a natural disaster which is an unpredictable and random hazard damages many lives and property. It is important to build the structures against earthquake forces to resist from deformation or collapse. From many decades, buildings are mostly constructed with RCC frames due to flexibility (Daniel et al., 2016). For this type of low-rise buildings Reinforced cement concrete (RCC) frames are sufficient to withstand lateral loads coming on them. But for high-rise buildings, RCC frames are not preferred due to the requirement of heavy mass of concrete leads to higher self-weight, restriction of span and risky formwork. So, steel and composite frames are used worldwide as they have got wide acceptance as a replacement for pure concrete and pure steel. High-rise structures became predominant due to rapid growth of industrialization and urbanisation (Sudarshan et al, 2018). Steel and composite frames are used for construction of high-rise structures due to light weight, speedy construction, less cost, protection against fire and higher ductility of steel. High-rise structures include high-rise buildings, bridges, towers, and industrial plants etc. Composite structures combine the compression nature of concrete and tensile nature of steel, makes the construction economical and effective.

Sudarshan et al.,2018 described that the composite frame starts yielding at a displacement of 223 mm which is 29.55% lesser than the displacement of steel frame and given that composite frame resist forces lesser time than steel frame. Saleem et al.,2020 determined that composite columns are very much useful to resist compressive loading and concluded that the plus plan of composite frame is the best frame for construction than triangular as well as square. Raut et al, 2014 presented that the pushover analysis is the best and simple procedure to analyse the non-linear seismic response of the structures. Limbare et al.,2018 discussed that the weight of the composite structure is approximately 25% lesser than RCC frame structure and time required for the construction of RCC structure is more than the composite structure. Panchal et al.,2011 described that composite frame is best suitable for the construction of high-rise buildings than RCC and steel frames and the weight of steel frame structure is 32% less than RCC frame structure. Daniel et al.,2016 given that the pushover analysis is the best method of giving the results of formation of plastic hinges at various levels of a high-rise structure. Tedia et al.,2014 determined that the cost of composite framed structure is more compare to RCC structure but the performance of composite frame is best than concrete structures. Aniket et al.,2016 determined that the composite frame is more economical than the Reinforced concrete frame and the speed of construction of composite frame is more and weight of steel frame is less than concrete frame.

Pandey et la.,2014 discussed that the steel frame has more storey drift in x-direction than the concrete, composite frame and the cost of construction of composite frame 33% lesser than concrete frame and cost of construction of steel frame is 27% lesser than concrete frame. Wagh et al.,2014 given that the performance of steel-concrete composite frame structure is better than the concrete frame under earthquake condition as the downward reaction and bending moment of composite frame structure is less and the size of the foundation required for composite frame is lesser compared to reinforced cement concrete frame. Kakpure et al.,2016 described that the value of storey drift of G+10 and G+25 is 22-25% lesser in dynamic analysis compared to static analysis and the displacement value increases gradually as there is an increase in height of storey. Thapa et al.,2020 determined that the materials required for reinforced cement concrete frame is more compared to steel frame and storey stiffness is more in case of steel compared to concrete and steel frame performs better during seismic condition than RCC frame as base shear is less for steel. Rajmani et al.,2015 concluded that the circular, triangular shapes are most suitable for G+15 structure under maximum earthquake, wind load condition and for G+30 building rectangular shape is mostly preferred against maximum earthquake and wind load. Pednekar et al.,2015 determined that as the number of storeys increases, base shear increases, spectral displacement increases and spectral acceleration increases.

2.Pushover analysis

Pushover analysis is a static procedure in which the structure is subjected to loading due to gravity and until an ultimate condition is reached there will a displacement in lateral direction in with pre-defined pattern. In this method, pre-defined pattern is indicated in terms of mode shape and shear of the storey. It is a method in which magnitude of structural loads are increased incrementally on the lateral direction of the structure. In this analysis, one can estimate the damage pattern of the building or structure. It is a simple procedure which provides the identification of data of critical members by ensuring strength, ductility and deformation of structure subjected to seismic excitation leads to the proper detailing and designing of the structure. This method develops the relation between force and the displacement (Pednekar et al., 2015). As the lateral load increases successively, the elements present in the structure taken on the load and weakens its body leads to the failure of the structure. After the failure of the structure, post elastic analysis can be adopted by designer and can make required corrections in design to acquire required sequence of plastic hinges under application of suitable lateral load. As the load is applied incrementally, the degradation of stiffness of each element and the force versus displacement data can be computed for the structure (Raut et al.,2014).

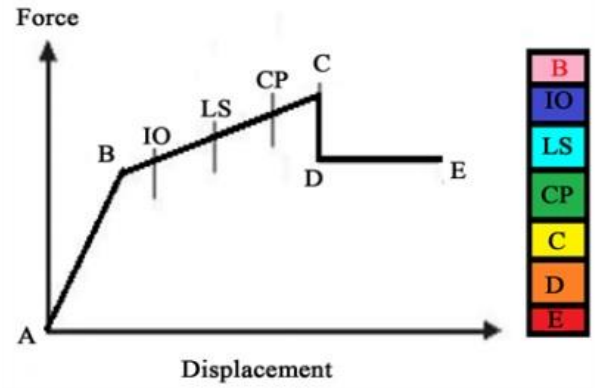

Fig.1 Pushover Curve

For the analysis of the structure using this method, load Vs displacement curve is necessary to obtain the points of performance and the location of hinges in various stages known as Pushover curve as shown in Fig.1 (Patil et al., 2020). This method is more convenient than the dynamic analysis as it requires less time for computation and this method is mostly used in design office for practical applications. In this curve, there is a representation for every range as follows:

A-B represents Elastic range
B-IO represents range of Instant Occupancy
IO-LS represents range of Life Safety
LS-CP represents range of Collapse Prevention

3.Different Frames used for structures

There are 3 different frames used for the construction of the structures. They are

1.RCC Frame
2. Steel Frame
3. Composite Frame

3.1 RCC Frame:

Reinforced cement concrete is a widely used material for the construction of both residential and commercial projects in India over many decades. Concrete is strong in compression and weak in tension, so to inbuilt the tensile strength to the concrete reinforcing bars or steel reinforcement is inserted as shown in Fig.2. These frames require large quantity of materials, workmanship and this is the reason why they are mostly used for low-rise buildings. So, the frames like steel and composite came into existence. RCC consists of cement concrete with reinforcing bars, in which load from slab is transferred to beams to columns to footing and to the soil. The mass of the concrete structures is heavier with lesser stiffness and ductility (Sudarshan et al.,2018).

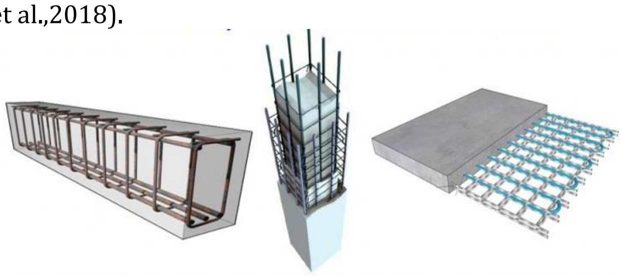

Fig.2 RCC Beam, Column and Slab

3.2 Steel Frame

Steel structure is made up of structural steel which consists of horizontal beam and vertical column creates the skeleton of steel. Horizontal element or beam is known as Flange and vertical element of column is known as Web as shown in Fig.3. Mostly I-section of structural steel are used for the construction and various civil engineering fields. These I-sections can be used in ways that is for column as well as beam. They are of many types and vary in depth, height, thickness, length and cross-section and selected based on the load carrying capacity and performance. This frame provides support to the walls, roof and floors of the structure. The elements in steel frame i.e., web resist shear forces and flanges resist bending moment. I-section is proved to be effective and efficient in carrying shear loads and bending moments in the plane of web by Beam theory. In transverse direction, this cross-section has lower capacity and it is ineffective in taking torsion. Steel structure is a superior material than RCC and composite due to its high ductility and ability to take seismic excitations. Steel Frame has an advantage of possessing tensile strength as well as compressive strength. Steel frame can be moulded into required shape, bolting and welding processes are used to connect each element during construction (Patil et al.,2020).

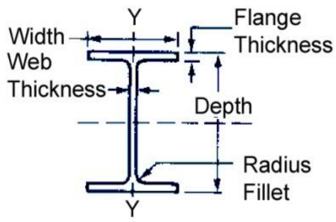

Fig.3 Steel I-Section

3.3 Composite Frame

In the past decades, the structures used to be made of masonry or concrete due to their low cost of construction and flexibility. During earthquake condition, many structures with concrete and masonry got collapsed which forced the structural engineers to look for alternative method for the construction of structures. The alternative method for the construction is the combination of structural steel and concrete known as Composite frame shown in Fig.4. Composite frame structure is formed by steel beam attached to a component of concrete i.e., Slab. In India, due to complexity in design of composite frames, most of the consultancies are not accepting them. But from literature, it can be seen that composite frame are proved to be most economical than RCC and steel frames if designed properly.

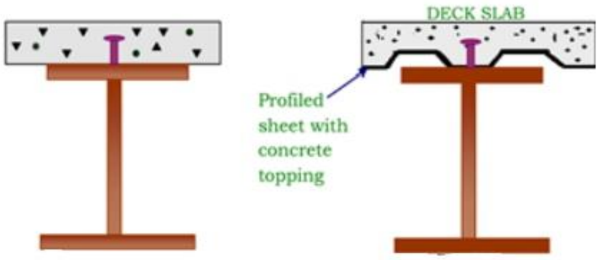

Fig.4 Composite frame with solid slab and deck slab

Composite frame leads to the higher durability and faster construction of structures. Composite frame combines the compressive strength of concrete and tensile strength of steel leads to economic construction. Shear connectors are used in composite construction as the total shear force at the interface of steel beam and concrete slab is about 8 times the total load carried by beam. Shear connector is used to prevent steel beam and concrete slab from separation ad it transmits longitudinal shear along their interface (Limbare et al., 2018). Composite frames have higher resistance to fire, greater flexibility, higher stiffness and does not require formwork (Wagh et al.,2014).

4.Comparison of RCC, Steel and Composite Frames using ETABS

Pushover analysis of a structure is carried out using ETABS software in which base shear, time period and formation of plastic hinges are observed. From Fig.5, it can bae seen that the lateral load is acting along the height of the high-rise structure and structure gets deformed due to the load. There will be displacement at the roof due to loading and shear will act at the bottom of the structure which resists the structure from deformation at bottom.

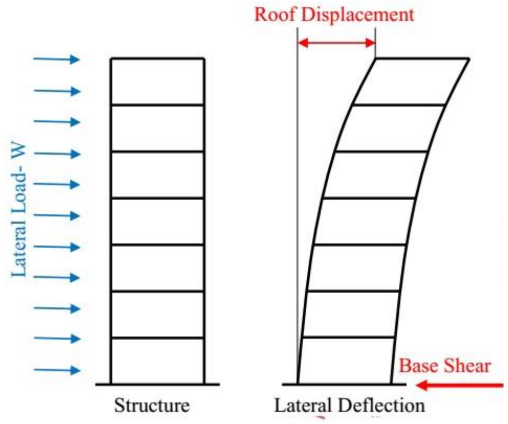

Fig.5 High-rise structure with displacement at roof

4.1 Analysis of G+15 Steel and Composite Frame structure (Sudarshan et al.,2018)

In this study, G+15 structure situated in Zone-V was analysed made of steel frame and steel-concrete (composite) frame using ETABS software. The total height of the structure was taken as 46.5 m in which each storey height was 3 m for floor to floor and 1.5 m from ground to floor. It was found that yield displacement is 316.57 mm for steel frame and 223 mm for composite frame. Maximum base shear of steel structure was 8400 kN and composite frame was 7717 kN. The time period for G+15 structure constructed with steel was 3.876 sec and with composite was 3.104 sec. It was found that the time required for oscillation of steel structure is more than composite structure as steel possess higher flexibility. Formation of plastic hinges are first in case of composite frames structure as composite frame has less ductility than steel framed structure. It was concluded that the steel frame is the best and safe choice for construction under seismic conditions.

4.2 Analysis of G+12 RCC and Steel Frame structure (Raut et al., 2019)

In this study, pushover analysis was carried for the G+12 RCC and Steel framed structures located in Zone-IV resting on rocky strata using ETABS software. The total height of building was taken as 40.5 m with each storey height of 3 m with 1.5 m plinth height. The live load on the structure was taken as 3 kN/m^2. The maximum displacement of RCC frame was found to be 32 mm and 414 mm at first and last hinge formation respectively. The maximum displacement of steel frame was found to be 135 mm and 920 mm at first and last hinge formation respectively. The base shear was found to be higher for RCC framed structure than Steel framed structure as reinforced cement concrete has more weight. The time period for G+12 steel frame was 5.92 sec and for RCC frame was 2.13 sec.

4.3 Analysis of G+20 RCC and Composite Frame structure (Limbare et al.,2018)

In this study, G+20 RCC and Composite framed structures are compared by analysing using STAAD-PRO. In this analysis Response spectrum and Equivalent static method are used in which structure is situated in Zone-II. The height of the structure was taken as 85 m with each storey height of 4.2 m. The weight of RCC framed structure was found to be 95566 kN and Composite frames structure was 73092 kN. The base shear of Composite structure was found to be 25% lesser compared to RCC. The time period of RCC structure was 2.9 sec and Composite structure was 3.45 sec. As the number of storeys increases, the displacement in x-direction increases and it is maximum in case of Composite framed structure. It was concluded that the storey drift is higher in case of RCC structure compared to composite structure.

Conclusions

As shear at bottom is considered, RCC structures performs better than steel and composite structures as it possesses higher dead load.

Steel structures are found to be more effective than composite and RCC framed structures due to lesser weight and higher ductility of steel.

Steel structures are used to resist the seismic forces for longer time than composite framed structures.

It was concluded that the composite structure is costlier than the RCC and steel structures but it performs well in case of earthquake condition.

The steel structure is the best and effective option than RCC structure but Composite structure performs effectively under seismic excitations.

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