International Journal of Advanced Engineering, Sciences and Applications (IJAESA) Volume 2, Issue 2 (2021), Pages 26-31
DOI: https://doi.org/10.47346/ijaesa.v2i2.69 ISSN: 2703-7266

Evaluation of elastic stiffness factor of 2D reinforced concrete frame system with different parameters

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ARTICLE INFO

ARTICLE HISTORY:

Received: 20 February 2021
Revised: 11 April 2021
Accepted: 04 May 2021
Published: 25 May 2021

KEYWORDS:

Elastic stiffness factor, base shear, pushover analysis, shear wall, number of stories, span length

ABSTRACT

In general, the buildings are designed based on the applied loads on them, and these buildings generally have elastic structural behaviour. However, these structures may be subjected to unexpectedly strong seismic forces that exceed their elastic limits. In order to find the rigidity and load-bearing trend of the building without the formation of plastic hinges and failure, pushover analysis should be performed. Pushover analysis is a non-linear static analysis in which the structure is subjected to lateral loads, so some parameters are recorded, such as failure, formation of plastic hinges, and yield. The elastic stiffness factor is the ability of a building to bear the loads on it before the failure and existent of the plastic hinges. In this study, pushover analysis had been done on 12 two-dimensional reinforced concrete frames with a different number of stories, different span lengths and with or without shear walls to find the effect of the span length, shear wall and the number of stories on the elastic stiffness factor. After performing the pushover analysis, the elastic stiffness factor had been evaluated from the pushover curve by dividing the base shear over the lateral displacement at the first point of the occurrence of the plastic hinge. The results obtained from the study showed that the elastic stiffness factor increases with the increase of the span length, while it decreases with the increase of the number of stories. As well, the frames with shear walls are stiffer than the frames without shear walls.

1. INTRODUCTION

The design in civil engineering depends on building codes. The aim of these codes is to provide safety for people. The method of designing according to the codes includes designing for lateral loads. The problem is that these lateral loads can be in the form of earthquakes, which are hard to predict. In general, the building structures are designed according to loads in which these structures will have elastic structural behaviour. However, these structures may be subjected to unexpectedly strong seismic forces that exceed their elastic limits. Under high forces, it is hard to give the expected performance of structures even if the codes can provide an indication of the performance of the structural elements (Rana et al., 2004). The lateral loads result in bending of the structure in which the base shear will increase till reach its maximum with the increase of the lateral displacement until the failure. Before the failure, a plastic hinge is formed, which is formed due to reaching the yield point of the structural member. In order to know the building stiffness and the ability to resist the loads without the formation of hinges and failure, pushover analysis should be done.

1.1. Pushover analysis

Pushover analysis can be considered as a non-linear static analysis in which the loads on the building increase according to another predefined pattern, and it is used to find the strength of the building (Wang & Ho, 2007). Pushover analysis is done by subjecting the frame to monotonically increasing lateral loads, these loads are applied in a step-by-step nonlinear static analysis and these loads are accelerated in the x-direction (Kadid & Boumrkik, 2008). Pushover analysis or static nonlinear analysis is a technique in which a computer model of a structure, which is exposed to different shapes of lateral load which can be parabolic, uniform or triangular. These lateral loads are increased slowly and with this increase, the yielding, plastic hinge formation, cracks, and failure are recorded (Abhilash et al., 2009). Pushover analysis is an efficient way of

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analysing the behaviour of buildings and recording the cracking, and the yielding with the increase of base shear value (Ambhaikar et al., 2018). Nonlinear static analysis shows the performance level, failure mechanism in the structure and the behaviour of components. Also, it provides information about the types of hinges formed, the capacity and strength of the weak components (Golghate et al., 2013).

1.1.1. Importance of pushover analysis

The importance of the pushover analysis can be summarized as follows:

- Estimation of the deformation of elements that have to deform in an inelastic way,
- Estimation of the inter-story drifts to know the stiffness and strength discontinuities which will help in controlling the damage on the non-structural members,
- Indication of the failure and yielding of the members,
- Identification of the adequacy of load path,
- Indication of the strength irregularities which cause variations in dynamic characteristics at the range of inelastic (Patil et al., 2017).

1.2. Elastic stiffness factor

The elastic stiffness factor of a building is the tendency to bear the loads that are applied to the structure without the formation of the plastic hinges and this factor can be used in order to evaluate the natural period of the building. This factor can be evaluated from the pushover curve observed from the pushover analysis by dividing the base shear over the lateral displacement at the first occurrence of the plastic hinge (Sarhan & Raslan, 2020).

$$K = Vs \,/\, Ds \tag{1}$$

where:

K: elastic stiffness factor,
Vs: base shear,
Ds: displacement.

2. SCOPE OF THE STUDY

The scope of the study is to find the influence of shear wall, span length and number of stories on the elastic stiffness factor.

3. MATERIALS AND SECTIONS

3.1. Materials properties

The materials used in this study are concrete and steel bars (Table 1). The concrete compressive strength f_c'(is 25 Mpa, modulus of elasticity E is 23,500 MPa and the unit weight is 25 kN/m^3. The strength of reinforcement steel bars f_y is 420 MPa and the modulus of elasticity is 200,000 MPa.

Table 1. Material properties

Properties	**Value**
f_c' (MPa)	25
f_y (MPa)	420
Unit weight of concrete (kN/m^3)	25
Modulus of elasticity of concrete (MPa)	23,500
Modulus of elasticity of steel (MPa)	200,000

3.2. Dimensions of sections

The frame sections are reinforced concrete columns, beams and shear walls. The depth and width for columns are 40 cm and 40 cm respectively while for the beams they are 40 cm and 25 cm respectively. The thickness of the shear wall is 25 cm (Table 2).

Table 2. Member's dimensions

Member	**Dimension**
Column	40 ×40 cm
Beam	40 × 25 cm
Shear wall	25 cm

4. METHODOLOGY

This research was conducted on 12 reinforced concrete frames with different parameters using ETABS software according to the AISC360-16 code (Table 2). These parameters are the number of stories, span length, with and without shear walls. Figs. 2 and 3 show samples of frames of this study. The dimensions of the beams and columns are the same for all frames. The numbers of stories are 4, 8 and 12. The span lengths were 5 and 6 meters and the story height for all frames is 3 meters. The gravity loads that have been applied on the frames are superimposed dead load of value 20 kN/m^2, a live load of value 25 kN/m^2 and the dead load (self-weight) which is calculated by the software. Frame hinges have been assigned to the beams and columns and wall hinges have been assigned to the shear wall.

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Table 3. Frames of study

Frames	Shear wall	Span length (m)	Story number
1	-	5	4
2	yes		
3	-	6	
4	yes		
5	-	5	8
6	yes		
7	-	6	
8	yes		
9	-	5	12
10	yes		
11	-	6	
12	yes		

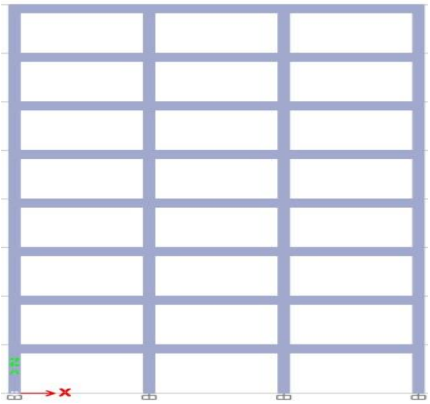

Fig. 1. Frame sample without shear wall

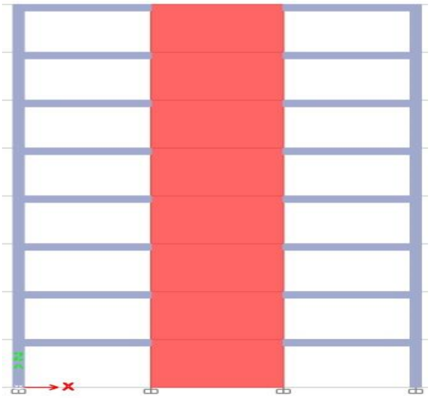

Fig. 2. Frame sample with shear wall

In this research, the ETABS software draws the push-up curve in the form of basic shear force relative to lateral displacement. By this curve, the elastic stiffness factor can be calculated at the existence of the first plastic hinge by finding the slope of it, which is the value of base shear over the lateral displacement and these values will be compared in order to understand how the shear wall, the number of stories and the span length affect the K factor.

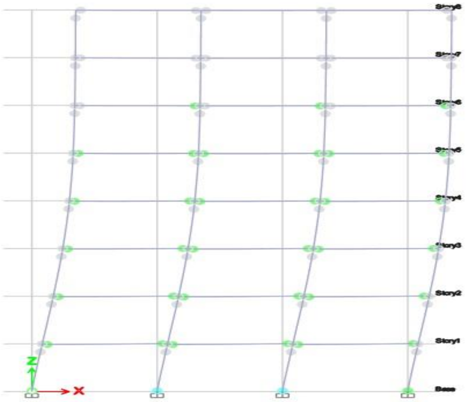

Fig. 3. Plastic hinge formation of a frame without shear wall

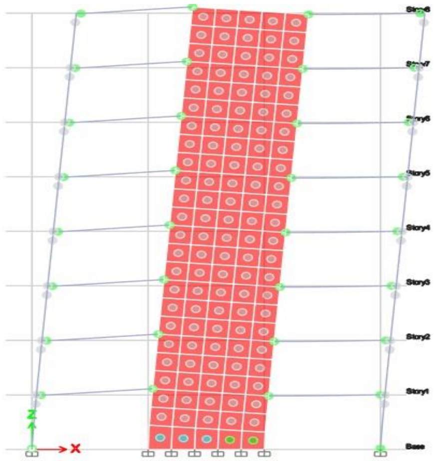

Fig. 4. Plastic hinge formation of a frame with shear wall

5. RESULTS AND DISCUSSIONS

Figs. 3 and 4 show the formation of the plastic hinges in frames with and without shear walls. After the pushover analysis, the software gave the base shear and the lateral displacement for each frame. The base shear for the frames from 1 to 12 is 131.23, 658.05, 180.32, 990.48, 116.16, 208.36, 59.46, 896.74, 101.46, 140.63, 33.12 and 367.81 kN respectively and the lateral displacement is 8.17, 2.498, 9.62, 2.98, 15.5, 4.02, 6.07, 12.61, 21.47, 6.58, 3.76 and 13.08 mm respectively.

The elastic stiffness factor had been calculated by dividing the base shear over the lateral displacement (Table 4).

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Table 4. K factor for frames

Frames	K factor (kN/mm)
1	16.06
2	263.43
3	18.74
4	332.38
5	7.49
6	51.90
7	9.83
8	71.11
9	4.73
10	21.37
11	8.81
12	28.12

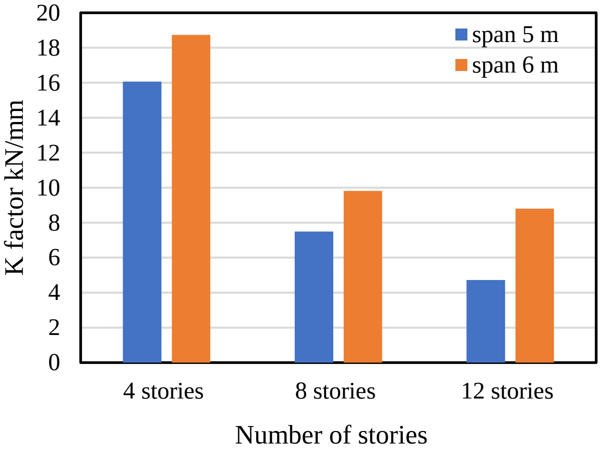

Fig. 5. K factor of frames without shear wall with different number of stories and span length

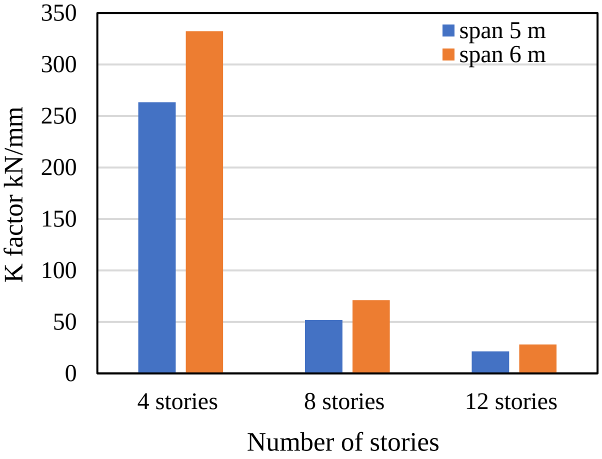

Fig. 6. K factor of frames with shear wall with different number of stories and span length

5.1. Influence of number of stories on elastic stiffness factor

For the frames, without a shear wall, the K factor at span length of 5 meters is 16.06, 7.49 and 4.73 kN/mm and for the frames with shear walls, the K factor at the same span length is 263.43, 51.9 and 21.37 kN/mm at 4, 8 and 12 stories respectively. In both cases with and without a shear wall, the elastic stiffness factor decreases with the increase of the number of stories Figs. 2 and 3. Sarhan and Raslan (2020) as well as Zehro & Jkhsi (2020) reported that the K factor decrease as the number of stories increased and when the displacement is at the first existent of the plastic hinge.

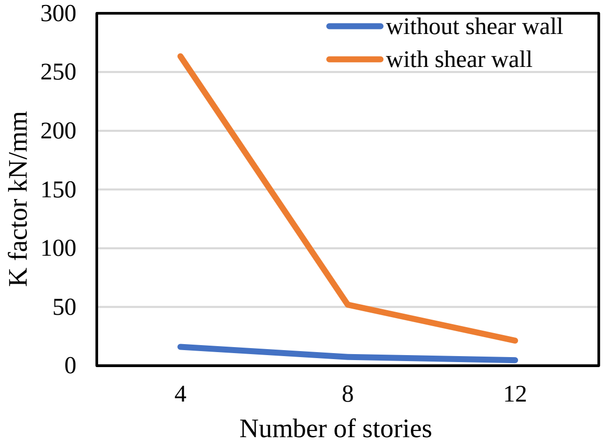

Fig. 7. K factor versus the number of stories with and without shear wall

5.2. Influence of span length on elastic stiffness factor

For the frames, without shear wall at 4 stories, the stiffness factor is 16.06, 7.49 and 4.73 kN/mm for span length 5 meter and 18.74, 9.83 and 8.81 kN/mm for span length 6 meters respectively. For the frames with shear walls wall at different story numbers 4, 8 and 12 stories the stiffness factor is 263.43, 51.9 and 21.37 kN/mm for span length 5 meters and 332.37, 71.11 and 28.12 kN/mm for span length 6 meters respectively. The frames with and without shear wall show the increase of elastic stiffness factor with the increase of span length from 5 to 6 meter as demonstrated in Figs. 2 and 3. Sarhan & Raslan (2020), as well as Kannas & Wafi (2020), reported that as the span length increase the elastic stiffness factor increase while on the other hand Zehro and Jkhsi (2020), as well as Alhassan and Abdelrahim (2020), reported that the increase of span length results in the decrease of the elastic stiffness factor.

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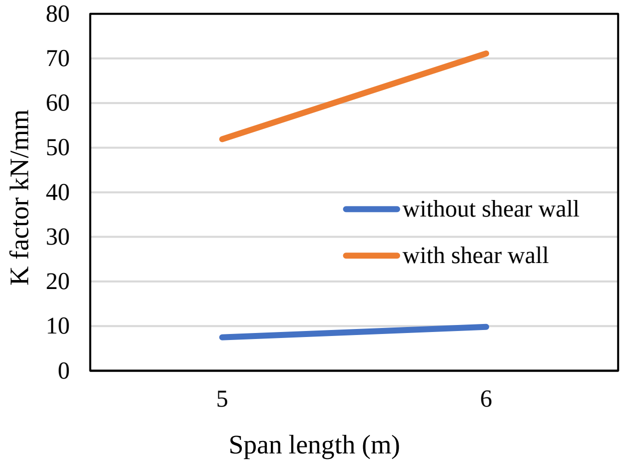

Fig. 8. K factor versus the number of stories with and without shear wall

5.3. Influence of shear wall on elastic the stiffness factor

Shear walls are vertical structural members of a structure that has the ability to resist the axial, shear and moment came from the gravity and the lateral loads and the presence of shear walls in a multi-story building is essential (Harne, 2014). Upon comparing the K factor with the same number of stories and same span length but with and without shear walls, it is obvious that the presence of shear walls gives higher K factors for the frames. Rahangdale and Satone (2013) reported that the shear walls are the most effective members in building to resist the lateral loads and the presence of them minimize the damages that can be occurred from the earthquakes. Mukundan and Manivel (2015) mentioned that the shear walls with and without openings are stable and strong and they are so efficient to resist the seismic loads. Ngenge and Wafi (2020) reported that when the shear wall is provided in the building the elastic stiffness factor of the building is more and the building became stiffer.

6. CONCLUSIONS

After performing the pushover analysis and evaluating the elastic stiffness factor from the pushover curve on twelve 2D reinforced concrete frames, the results showed that when the number of stories of the frame increase with and without shear wall, the elastic stiffness factor decreases. Moreover, as the distance between the columns in the frame increases with or without shear walls, the result is an increase in the elastic stiffness factor. The frames with shear walls give an elastic stiffness factor to the frames more than the frames without shear walls so it can be stated that the relation of elastic stiffness factor is directly proportional with the span length and inversely proportional with the number of stories. Finally, it can be concluded that the building becomes stiffer with shear walls and with higher span length but with few stories.

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