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RESEARCH ARTICLE

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SEISMIC ANALYSIS OF A STEEL BUILDING AGAINST EARTHQUAKE LOADS

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ABSTRACT

Steel is one of the most widely used material for building construction in the world .In Modern construction, steel is playing vital role as a building material either with combination of concrete as RCC or alone. The inherent properties of steel like strength, toughness, high ductility and other compatible properties made steel the first choice for engineers and also made the characteristics that are ideal for seismic design. To utilize these advantages for seismic applications, the design engineer has to be familiar with the relevant steel design provision and their intent given in codes. The seismic design of building frame presented in this project is based on: IS 1893-2002 and IS 800- 2007 codal provisions are considered for the design and for analysis STAAD Pro is used. The aim of present work is to analyze and design of a multi-bay and multi storied (G+5) steel structure for earthquake forces following IS 1893-2002 and design as per IS 800-2007.The selection of arbitrary sections have been done following a standard procedure and corrections are done accordingly for earthquake loads. Finally, the design of connection of an interior joint and an exterior joint of the frame have been done and the cost efficiency of both the methods has been compared.

Keywords: Seismic design, Equivalent static load method, Response Spectrum method and P-Δ analysis.

INTRODUCTION

Different types of loads such as dead, live, snow, wind, and seismic loads have been considered in building codes for decades. Seismic loads are one of the most uncertain types of loads that building codes have required engineers to consider in the design of buildings for many years. There have been a considerable amount of research work and study on different aspects of earthquakes and their consequent effects on the buildings in order to provide engineers with simple and practical instructions for performing a seismic design.

In modern times, many multi-storey buildings in cities are in high demand owing to increase in population in one hand and limited available space in the country in general and cities in particular on the other hand. Recent advances in the technology are also encouraging us to go for multi-storey buildings. Such multi-storey buildings demand for extra safety while its construction as well as its performance after it has been constructed [1]. Severe earthquakes occur relatively infrequently. Although it is technically possible to design and construct buildings for these earthquake events, it is generally considered uneconomical and un-necessary to do so. The seismic design is performed with the anticipation that the severe earthquake would cause some damage and a seismic design philosophy on this basis has been developed over the years. Seismic Analysis is a subset of structural analysis and is the calculation of the response of a building structure to earthquakes. It is part of the process of structural design, earthquake engineering or structural assessment and retrofit in regions where earthquakes are prevalent. The most important earthquakes are located close to the borders of the main tectonic plates which cover the surface of the globe. These plates tend to move relative to one another but are prevented by doing so by friction until the stresses between plates under the epicenter point become so high that a move suddenly takes place. This is an earthquake. The local shock generates waves in the ground which propagate over the earth's surface, creating movement at the bases of structures. The importance of waves reduces with the distance from the epicenter. Therefore, there exists region of the world with more or less high seismic risk, depending on their proximity to the boundaries of the main tectonic plates [2].

Steel structures are good at resisting earthquakes because of the property of ductility. Experience shows that steel structures subjected to earthquakes behave well. Global failures and huge numbers of casualties are mostly associated with structures made from other materials. This may be explained by some of the specific features of steel structures. There are two means by which the earthquake may be resisted:

Option 1: structures made of sufficiently large sections that they are subject to only elastic stresses

Option 2: structures made of smaller sections, designed to form numerous plastic zones.

A structure designed to the first option will be heavier and may not provide a safety margin to cover earthquake actions that are higher than expected, as element failure is not ductile. In this case the structure's global behavior is „brittle" and corresponds for instance to concept [3].

a. In a Base Shear V- Top Displacement diagram. In a structure designed to the second option selected parts of the structure are intentionally designed to undergo cyclic plastic deformations without failure, and the structure as a whole is designed such that only those selected zones will be plastically deformed.
b. The structures global behavior is "ductile" and corresponds to concept
c. in the Base Shear V- Top Displacement d. The structure can dissipate a significant amount of energy in these plastic zones, this energy being represented by the area under the V-d curve. For this reason, the two design options are said to lead to "dissipative" and "non-dissipative" structures.

A ductile behavior, which provides extended deformation capacity, is generally the better way to resist earthquakes. One reason for this is that because of the many uncertainties which characterize our knowledge of real seismic actions and of the analyses we make, it may be that the earthquake action and/ or its effects are greater than expected. By ensuring ductile behavior, any such excesses are easily absorbed simply by greater energy dissipation due to plastic deformations of structural components. The same components could not provide more strength (a greater elastic resistance) when option 1 is adopted. Furthermore, a reduction in base shear V(V reduced < V elastic) means an equal reduction in forces applied to the foundations, resulting in lower costs for the infrastructure of a building [4].

Steel structures are particularly good at providing an energy dissipation capability, due to:

- The ductility of steel as a material
- The many possible ductile mechanisms in steel elements and their connections
- The effective duplication of plastic mechanisms at a local level
- Reliable geometrical properties

The storey height is 3 meters and the horizontal spacing between bays is 8 meters and lateral spacing of bays is 6 meters

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The seismic parameters of building site are as follows

- Seismic zone: 3
- Zone factor : 0.16
- Response reduction factor: 5
- Importance factor:1.5
- Damping ratio: 3%

Experimental Details:

Design parameters:

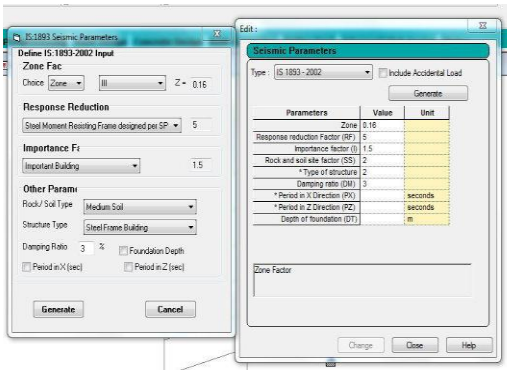


Figure 1: STAAD input of seismic parameter

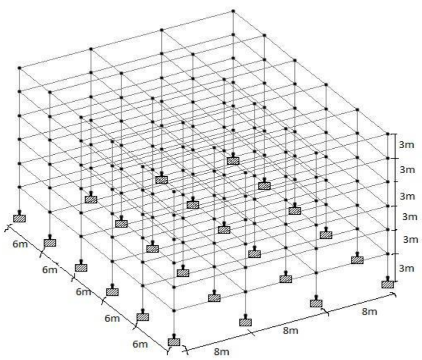


Figure 2: 3-dimensional view of the steel building frame

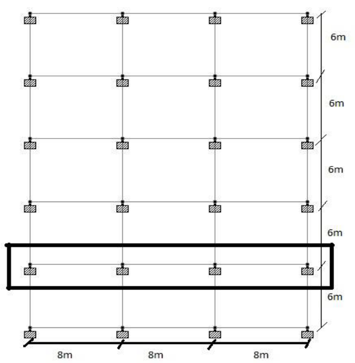


Figure 3: Plan of the building frame

LOAD PARAMETERS: Dead load is taken as = 5 KN/m^2 and live load is taken as 3 KN/m^2

Load Calculation

Figure 4: Elevation of the building frame

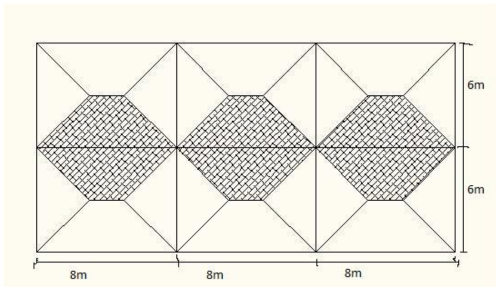


Figure 5: Load distribution diagram

Load on beam along horizontal direction

1. Dead Load = 30m2 5KN/m2 = 150KN

Uniformly Distributed Load = 150/8 = 18.75KN/m

2. Live Load = 30 3 = 90KN

Uniformly Distributed Load = 90/8 = 11.75KN/m

Load combinations as per IS1893-2002:

- 1.7(DL+LL)
- 1.7(DL+EQ)
- 1.7(DL-EQ)
- 1.3(DL+LL+EQ)
- 1.3(DL+LL-EQ)

After obtaining the seismic forces acting at different levels, the forces and moments in different members can be obtained by using any standard computer program for various load combinations specified in the code. The structure must also be designed to resist the overturning effects caused by seismic forces. And also storey drifts, member forces and moment due to P- delta effect must be determined. IS 1893 stipulates that the storey drift in any storey due to the minimum specified lateral loads , with a partial load factor of 1.0 should not exceed 0.004 times the storey height.

Table 1: Analysis by lateral force method

Storey no.	Absolute displacement of storey D_i (m)	Design inter storey drift D_r (m)	Storey lateral force V_{tot} (KN)	Shear at storey P_{tot} (KN)
1	0.003869	0.003869	1.969	179.201
2	0.012595	0.008726	7.951	177.232
3	0.023837	0.011242	17.83	169.281
4	0.035892	0.012055	31.657	151.451
5	0.047566	0.011674	49.212	119.794
6	0.058123	0.010557	70.582	70.582

RESPONSE SPECTRUM ANALYSIS

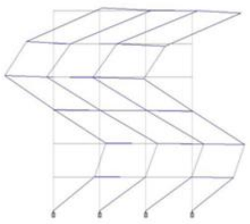
Response is obtained by using different modal combination methods such as square-root-of-sum-of-squares method (SRSS)or the complete quadratic method (CQC) which are used when natural periods of the different modes are well separated (when they differ by 10% of the lower frequency and the damping ratio does not exceed 5%.The CQC is a method which can account for modal coupling methods suggested by IS 1893.

Table 2: Analysis by response spectrum method

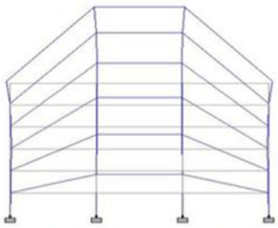
Storey no.	Absolute displacement of storey D_i (m)	Design inter storey drift D_r (m)	Storey lateral force V_{tot} (KN)	Shear at storey P_{tot} (KN)
1	0.00491	0.00491	1.877	120.981
2	0.0115	0.0066	6.112	119.104
3	0.0161	0.0046	10.651	112.992
4	0.0196	0.0035	17.331	102.341
5	0.0219	0.0023	29.98	85.01
6	0.0234	0.0015	55.03	55.03

Mode 1 (1.592 Hz), Modal Participation factor MPF= 85.33

Mode 2 (5.224 Hz), Modal Participation factor MPF= 81.3



Mode 3 (9.525 Hz), MPF 0



Mode 4 (12.796 Hz), MPF 0.01

Table 3: Base shear and mass participation factor

MODE	BASE SHEAR(KN)	Mass participation factor
1	252.75	85.33
2	27.8	8.13
3	12.1	3.54
4	0	0
5	0.02	0.01
6	5.85	2.04

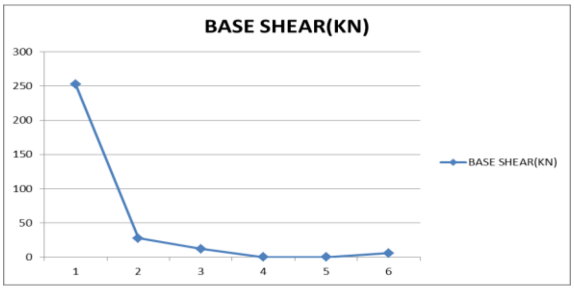


Figure 6: Graph of modes Vs base shear

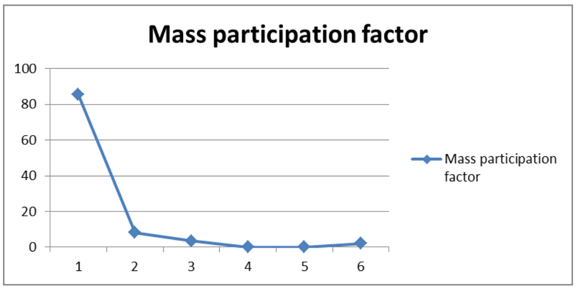


Figure 7: Graph of mass participation factor

P-Δ ANALYSIS: The P-Δ effect refers to the additional moment produced by the vertical loads and the lateral deflection of the column or other elements of the building resting lateral forces.

Table 4: Correction for P-Δ effect (lateral force method)

Storey no:	Absolute displacement of the storey D_i (m)	Design inter storey drift D_r(m)	Storey lateral forces	Shear at storey V_{tot}(KN)	Total cumulative gravity load at storey P_{tot} (KN)	Storey height: H_i(m)	Inter storey drift sensitivity coefficient: (θ)
1	0.003869	0.003869	1.969	179.201	7344	3	0.05285
2	0.012595	0.008726	7.951	177.232	6120	3	**0.10043***
3	0.023837	0.011242	17.83	169.281	4896	3	**0.10838***
4	0.035892	0.012055	31.657	151.451	3672	3	0.09742
5	0.047566	0.011674	49.212	119.794	2448	3	0.07951
6	0.058123	0.010557	70.582	70.582	1224	3	0.06102

Table 5: Correction for P-Δ effect, (response spectrum analysis)

Storey no:	Absolute displacement of the storey D_i (m)	Design inter storey drift D_r(m)	Storey lateral forces	Shear at storey V_{tot}(KN)	Total cumulative gravity load at storey P_{tot} (KN)	Storey height: H_i(m)	Inter storey drift sensitivity coefficient: (θ)
1	0.00491	0.00491	1.877	120.981	7344	3	0.09935
2	0.0115	0.0066	6.112	119.104	6120	3	**0.11304***
3	0.0161	0.0046	10.651	112.992	4896	3	0.06644
4	0.0196	0.0035	17.331	102.341	3672	3	0.04186
5	0.0219	0.0023	29.98	85.01	2448	3	0.02207
6	0.0234	0.0015	55.03	55.03	1224	3	0.01112

*Beams in this storey failed to satisfy P-Δ effect

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From the above table checks are made on the limitation of P-Δ effects with the results from the lateral force method. The value of resultant base shear is: 179.201KN ϴ <0.1 at storey's 1,4,5,6. Bending moment and other action effects found from the analysis at storey's 2 and 3 have to be increased by 1/(1-ϴ (1.11at storey 2 and 1.12 at storey 3) The maximum bending moment is at storey 2 : 230.172KN/m With the 1/(1-ϴ) increase: 1.11164×230.172=255.868KN/m.

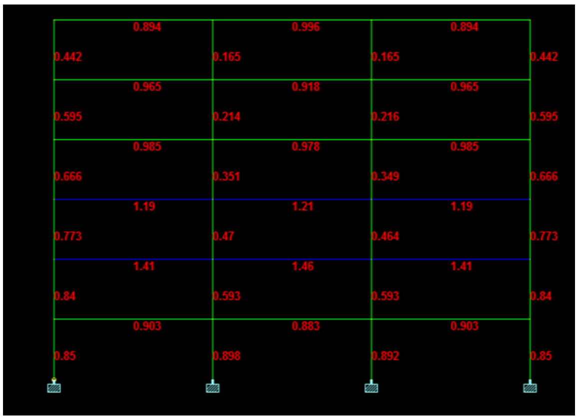

Figure 8: Diagram showing failed members

3.7.1 DESIGN STRENGTH

Table 6: Table of members failed and modified sections (by lateral force method)

Sl no.	Failed member no:	Failed section	Critical condition	Staad design section(passed)
1	1	ISMB350	IS 6.2	ISWB500
2	3,8,11,14,15	ISMB350	IS 6.2	ISLB550
3	10,12,17	ISMB350	IS 7.1.2	ISWB600
4	13	ISMB350	IS 6.2	ISHB450A
5	4,5,6,7,9,16,18	ISMB350	IS 7.1.2	ISWB600A
6	2	ISMB350	IS 6.2	ISHB450

Table 7: Table of member's failed and new modified sections (by response spectrum

Sl no.	Failed member no:	Failed section	Critical condition	Staad design section(passed)
1	1,13	I80012B50012	IS 7.1.2	I80012B50016
2	2,14	I80012B50012	IS 7.1.2	I0012B55012
3	3,15	I80012B50012	IS 7.1.2	ISWB550
4	7,8,9,40,42	ISMB350	IS 6.2	I100012B50012
5	21	I80012B50012	IS 7.1.2	I100012B50012
6	27	I80012B50012	IS 7.1.2	ISWB600A
7	41	ISMB350	IS 6.2	ISMB600

RESULTS OF LATERAL FORCE METHOD: Maximum bending moment, shear force etc. are obtained for load combination 1.7(EQ+DL)

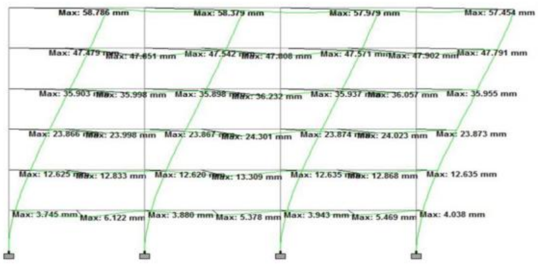

Figure 9: Displacement diagram for load combination 1.7(EQ+DL)

The inter storey drift as seen from above diagram is within the limits of deflection of the code i.e. it is within .004 of storey height= 0.004X3000= 12mm.

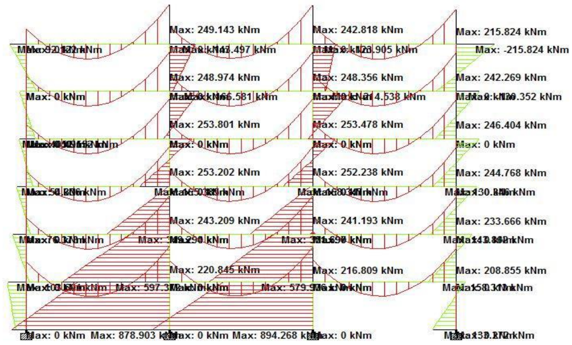

Figure 10: Bending moment diagram for load combination 1.7(EQ+DL)

RESPONSE SPECTRUM ANALYSIS: Maximum bending moment, shear force etc. are obtained for load combination 1.3(DL+LL+EQ)

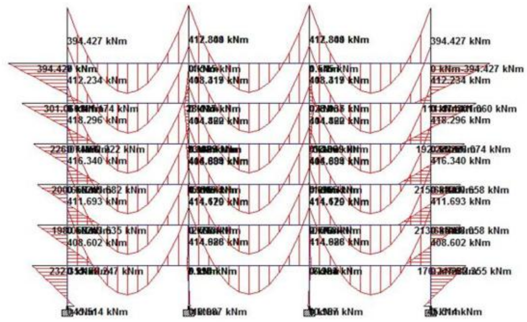

Figure 11: Bending moment diagram for load combination 1.3(DL+LL+EQ)

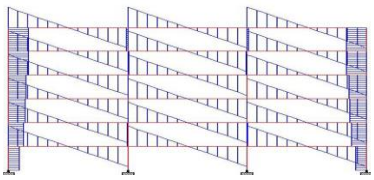

Figure 12: Shear force diagram in X-axis

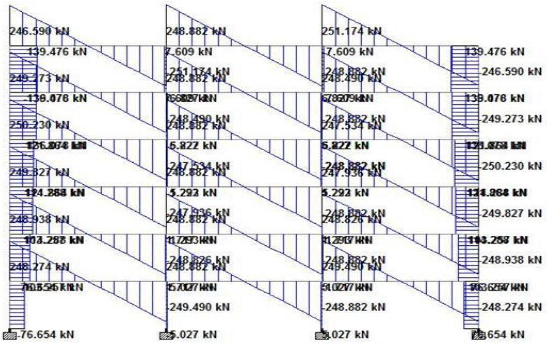

Figure 13: Axis shear force diagram in Y-axis

Table 8: Comparison of absolute storey drift in both methods

Storey no.	Storey height	LSM(cm)	RSA(cm)
1	3	0.3869	0.491
2	6	1.2595	1.15
3	9	2.3837	1.61
4	12	3.5892	1.96
5	15	4.7566	2.19
6	18	5.8123	2.34

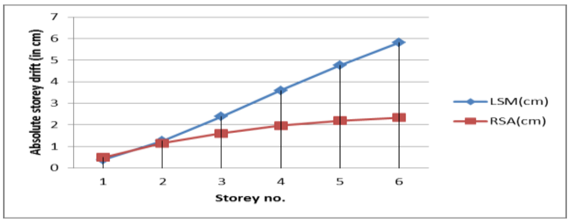

Figure 14: Graph of comparison of absolute storey drift

Table 9: Comparison of storey shear: (using both LSM and RSA)

Storey no.	Storey height	LSM (KN)	RSA (KN)	Difference in %
1	3	179.201	120.981	28.91
2	6	177.232	119.104	32.79
3	9	169.281	112.992	33.25
4	12	151.451	102.341	32.42
5	15	119.794	85.01	28.99
6	18	70.582	55.03	22.033

It is found that the difference storey shears by both these methods are about 29.73 %at an average per storey.

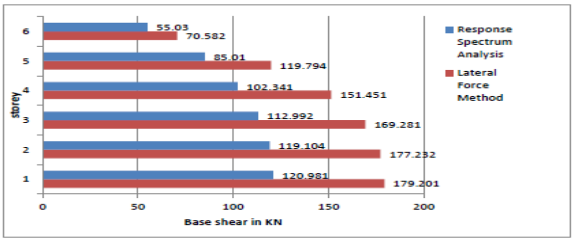

Figure 15: Graph of comparison of storey shear

Table 10: Drift by Lateral Force Method

Storey no.	Pre design drift (cm)	Post design drift(cm)	Difference in %
1	0.3869	0.2056	46.85
2	1.2595	0.5472	56.55
3	2.3837	0.9052	68.11
4	3.5892	1.2561	65
5	4.7566	1.5729	66.93
6	5.8123	1.8012	69.05

It is observed that the difference in drift in post and pre design is almost as high as 62.08% at an average per storey.

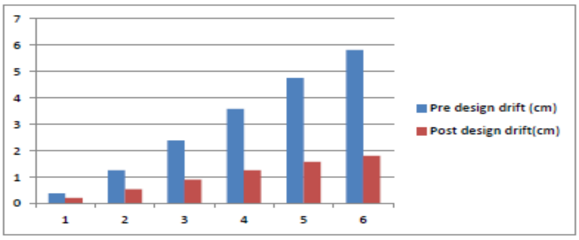

Figure 16: Graph of storey drift for final and initial design results

Response Spectrum Method:

Participation factor: Total amount of steel required in the form of connections and member sections are more for analysis and design based on response spectrum method than lateral force method.

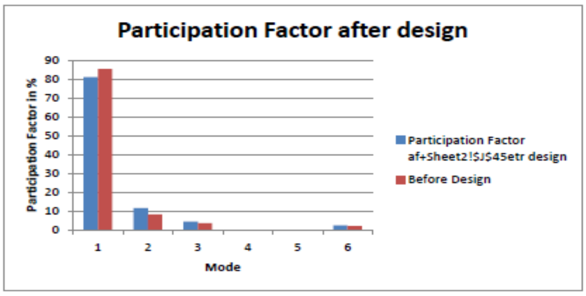

Figure 17: Graph of mode participation for final and initial design results

CONCLUSIONS

- Inter storey drift was found out using lateral force method and response spectrum method and it was found that the displacements of response spectrum method was less than that of lateral force method.
- Storey shear found by response spectrum method is less than that found by lateral force method.
- The difference in results of response spectrum and lateral force method are attributed to

certain assumptions prevalent in the lateral force method. They are:

- The fundamental mode of the building makes most significant contribution to the base shear.
- The total building mass is considered as against the modal mass that is used in dynamic procedure. Both the assumptions are valid for low and medium rise buildings which are regular.

- As observed in the above results the values obtained by following dynamic analysis are smaller than those of lateral force method. This is so because the first mode period by dynamic analysis is 0.62803 is greater than the estimated 0.33 s of lateral force method.
- The analysis also shows that the first modal mass is 85.33% of total seismic mass. The second modal mass is 8.13% of the total seismic mass m and the time period is 0.19s.
- The amount of steel required for seismic design by using lateral force method is found to be 19.73% less than that by using response spectrum analysis
- Because of the heavier sections used in response spectrum method the absolute displacement, storey drift are less than lateral force method
- It is found that the inter storey drift sensitivity coefficient θ does not differ much in both the methods of analysis
- The values of resultant base shear in lateral force method is 49.33 % more than that of response spectrum method

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