Steel Structures in Context of Safety, Resilience & Sustainable Construction: Minimizing Environmental Impacts

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Abstract:- The study analyzes a G+4 residential building subjected to seismic loads, comparing vertical base shears, material strengths, and foundation design requirements. The results reveal that RCC structures generate significantly higher vertical base shears due to their heavier loads, necessitating larger foundation areas, especially at critical points, and leading to increased construction costs. In contrast, Steel structures, with lower base shears, require smaller foundation areas, reducing both material use and environmental impact. The findings emphasize that Steel structures offer superior seismic performance, cost efficiency, and sustainability by minimizing foundation requirements and associated environmental burdens. This research highlights the importance of material choice in achieving resilient and sustainable construction, particularly in seismic zones, where Steel structures provide a more efficient and environmentally friendly solution compared to RCC structures.

Keywords:- *Steel Structure, Seismic Safety, Eco-Friendly Materials, Sustainable Construction.*

I. INTRODUCTION

There have been concerns expressed about the necessity of improving building methods to lessen their negative impact on the environment. Building experts worldwide have focused a great deal of emphasis on the environmental effect of construction, the creation of green buildings, planning for recyclability, and choosing eco-friendly building materials. Every conventional element of a building project has an evident effect on the environment, from the methods used to extract minerals in mining to the garbage generated throughout the project and how it is eliminated, five percent of the world's emissions of carbon dioxide are caused by the cement industry alone. [1] Raw building materials in construction are also quite energy-intensive to transport, especially for countries like Singapore that import a lot of these resources.[2] The industry of construction is resource-, waste-, and energy-intensive. Over half of the raw materials extracted globally are used by it,[3] generates 35.9% of waste in the EU[4], produces 160 million tons, or 25 percent, of non-industrial waste per year in the U.S.[5] , emits the most carbon dioxide of any industry, and accounts for 40 percent of all energy used in buildings globally.[6] The substantial CO2 emissions are contributing to the gradual rise in global temperatures, making sustainability the essential solution for preserving the planet. The sustainable development movement has been evolving for almost 25 years worldwide. It was The Brundtland Report (1987) of The United Nations World Commission on Environment and Development that first popularized the phrase "sustainable development" by defining it as the “development that meets the needs of the present without compromising the ability of future generations to meet their own needs”[7] With time the literal application of this term has been, it has grown in scope and maturity. Environmental protection is now viewed as just one aspect of sustainable growth that encompasses both economic and social aspects. Two of the main materials used in the building industry are steel and concrete, both of which are known for having significant embodied energy. The industry may reduce its environmental effect by carefully choosing between these two materials. In light of the global sustainability movement, the conventional cost-centric selection methodology falls short, underscoring the imperative for the implementation of a structured system for supporting decisions. In terms of sustainability, durability, and longevity, steel is a superior choice compared to concrete. It should be noted that approximately 9% of the global carbon dioxide emissions can be attributed to the specific production processes of this material. Compared to other conventional building materials, steel exhibits a unique ecological advantage due to its exceptional recyclability.[8] Two examples of recycling in construction materials are the use of crushed concrete as foundation aggregate material and the repurposing of old tires into rubberized asphalt. These recycled products do not achieve the same level of utility as the original materials. However, steel is an exception to this rule, as it can be recycled multiple times to produce goods that maintain the same high quality as those manufactured from raw materials.[9]

➢ *Purpose of Sustainable Construction:*

Sustainable construction, also known as green building or eco-friendly construction, aims to minimize the environmental impact of building projects throughout their entire lifecycle, from design and construction to operation and demolition. The requirement for sustainable development in the construction industry has got importance in the last decade due to the major resource consumption and contamination buildings generate and other damages such as large quantities of waste, energy consumption, noise caused by construction operations etc. The purpose of sustainable construction is multifaceted:

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- **Grow Resource Efficacy:** Sustainable construction aims to optimize the use of resources such as energy, water, and materials. This involves employing strategies like using recycled or renewable materials, designing for durability, and minimizing waste during construction.
- **Environmental Protection:** By reducing resource consumption and minimizing pollution, sustainable construction helps protect ecosystems, wildlife, and natural habitats. It mitigates the depletion of natural resources and helps preserve biodiversity.
- **Boost Energy Efficiency:** Sustainable buildings are designed to consume less energy for heating, cooling, lighting, and powering appliances. This often involves incorporating energy-efficient technologies like solar panels, high-performance insulation, and energy-efficient HVAC systems.
- **Reduced Emission:** Sustainable construction aims to minimize greenhouse gas emissions associated with the construction process and building operations. This includes using low-emission materials, optimizing transportation of materials to reduce carbon footprint, and promoting alternative transportation options for occupants.
- **Water Conservation:** Sustainable construction implements measures to reduce water consumption through efficient plumbing fixtures, rainwater harvesting systems, and greywater recycling. This helps conserve freshwater resources and reduces the strain on local water supplies. Compare to concrete steel doesn't require any water supply to prepare mixer or curing after manufacture.

➢ *Inventory Consumption & Emission [Concrete & Steel]*

Life-cycle energy consumption and environmental emissions of building materials in the present study, the concrete is assumed to be one-off due to its significantly low recovery rate. The recovery rate of steel is very high; thus, its production can be considered be of electro smelting of steel., Data of energy consumption and environmental emissions of steel come from "China Iron and Steel Industry Annual (1998)". Based on the assumption above and data used, BESLCI program is performed to obtain the inventory data. Table 2 shows that the life-cycle energy consumption of materials for steel-construction building is 75.1% as that for concrete-construction building. It is also shown that the CO2 emission of the steel-framed building is 48.1% less than that of concrete-construction building, and the SOX urban emission is 51.6% less than that of later.

Table 1 Consumption

Ingredients	Concrete-construction	Steel-construction	Relative percentage (steel/concrete (%)
Mineral consumption (kg/m2)	487.0	107.4	21.5
Energy consumption (kJ/m2)	3911861	2936920	75.1
Fossil fuel consumption (kJ/m2)	3910766	2935195	75.1

Table 2 Emissions (g/m2)

Ingredients	Concrete-construction	Steel-construction	Relative percentage (steel/concrete (%)
PM	1436.5	527.0	36.7
Sox	2051.3	1401.1	68.3
NOx	966.8	784.0	81.1
CO	1262.4	411.4	32.6
-NHMC	8.5	4.2	49.9
CH4	3.9	3.3	84.0
N2O	3.3	2.3	70.9
CO2	606000	314548	51.9

Table 3 Urban Emissions (g/m2)

Ingredients	Concrete-construction	Steel-construction	Relative percentage (steel/concrete (%)
PM	33.8	12.1	35.8
SO**x**	128.4	62.2	48.4
NOx	70.9	42.7	60.3
CO	24.4	10.7	43.6
NHMC	2.1	0.7	34.4

For the emissions of environmental burden are various, some emissions in concrete-construction building are larger than those in steel-construction building while other emissions are less. And the impacting of each emission to environment is different even if the quantity is same. So, the impact assessment is needed to quantify the environmental burden of these two buildings. The impact of emissions to environmental impacting is classified into energy exhaustion potential (mineral fuel exhaust), globe warming potential (greenhouse gas emissions), atmosphere environment impact (total contamination emissions) and urban atmosphere environment impact (urban contamination emissions). The energy exhaustion potential and globe warming potential are characterized by the equivalent method (Wang M Q 1999). The atmosphere environment impacting is characterized by the critical volume dilution method (Postlethwaite D 1996).

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In this paper, the atmosphere environment impacting and urban atmosphere environment impacting are calculated based on the contamination emissions standard of three regions prescribed by Chinese Environmental Quality Standard.[11] Table 2.3 shows the result on environmental impact assessment and the comparison of LCIA between concrete-building and steel-construction building. It shows that the total environmental burden of steel-construction building is a slightly higher than that of steel construction building. The proportion of life cycle energy consumption of building materials is 16.9% in concrete-construction building, while in steel- construction building is 11.8%. And the other three indexes, the proportion of building materials in concrete-construction building are all larger than in steel-construction building.

Table 3 Comparison of LCIA between Concrete-Building and Steel-Construction Building (g/m2)

	Concrete		Steel	
	Building materials	Use phase	Building materials	Use phase
Energy exhaustion potential	0.17	0.83	0.13	0.95
Globe warming potential	0.20	0.80	0.12	0.92
Atmosphere environment impact	0.22	0.78	0.14	0.91
Urban atmosphere environment impact	0.13	0.87	0.06	0.95
Total	0.72	3.28	0.45	3.73
	4		4.19	

➢ *Project Information*

[10] For a G+4 residential building with live, floor, and roof loads of 40 psf, 20 psf, and 20 psf, respectively, and considering a seismic zone factor (Z) of 0.15, design for RCC and Steel structures using fc = 3000 psi, fs = 40000 psi, and Steel I section of grade 40. Soil bearing capacity is 3 ksf. Seismic design includes R = 5.0, I = 1.0, and S = 1.0.

➢ *Compression of Strength & Resilience [Concrete & Steel]*

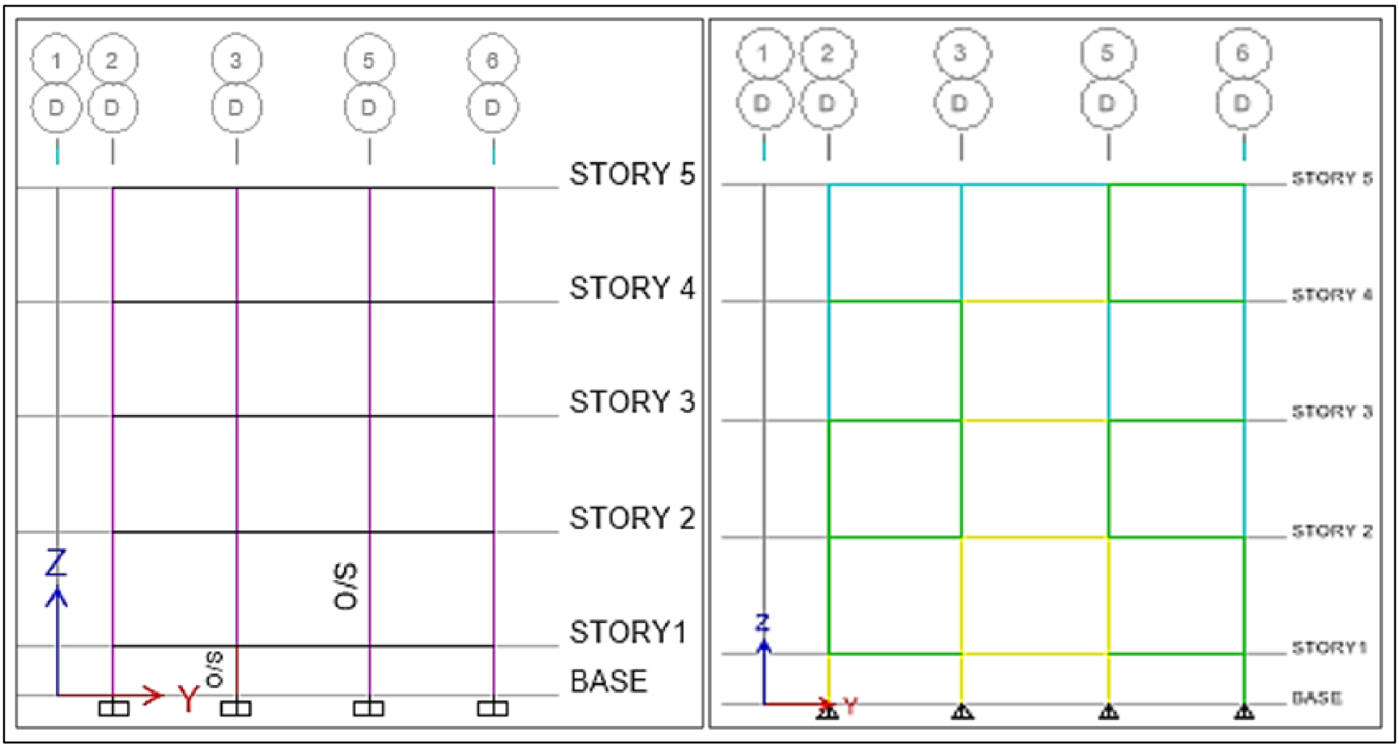

Fig 1-2 Checking Failure Members & Comparing between RCC and STEEL Structures

After analysis the result found a maximum amount of shear comes in two central column sections at grid D have shown in Figure 01. Structures are designed by following the codes ACI-318-08 & AISC-360-10 and which are equivalent. All sections are OK for AISC-360-10 but two number of sections are not OK and need to be re-design for ACI-318-08.

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- *Deflection*

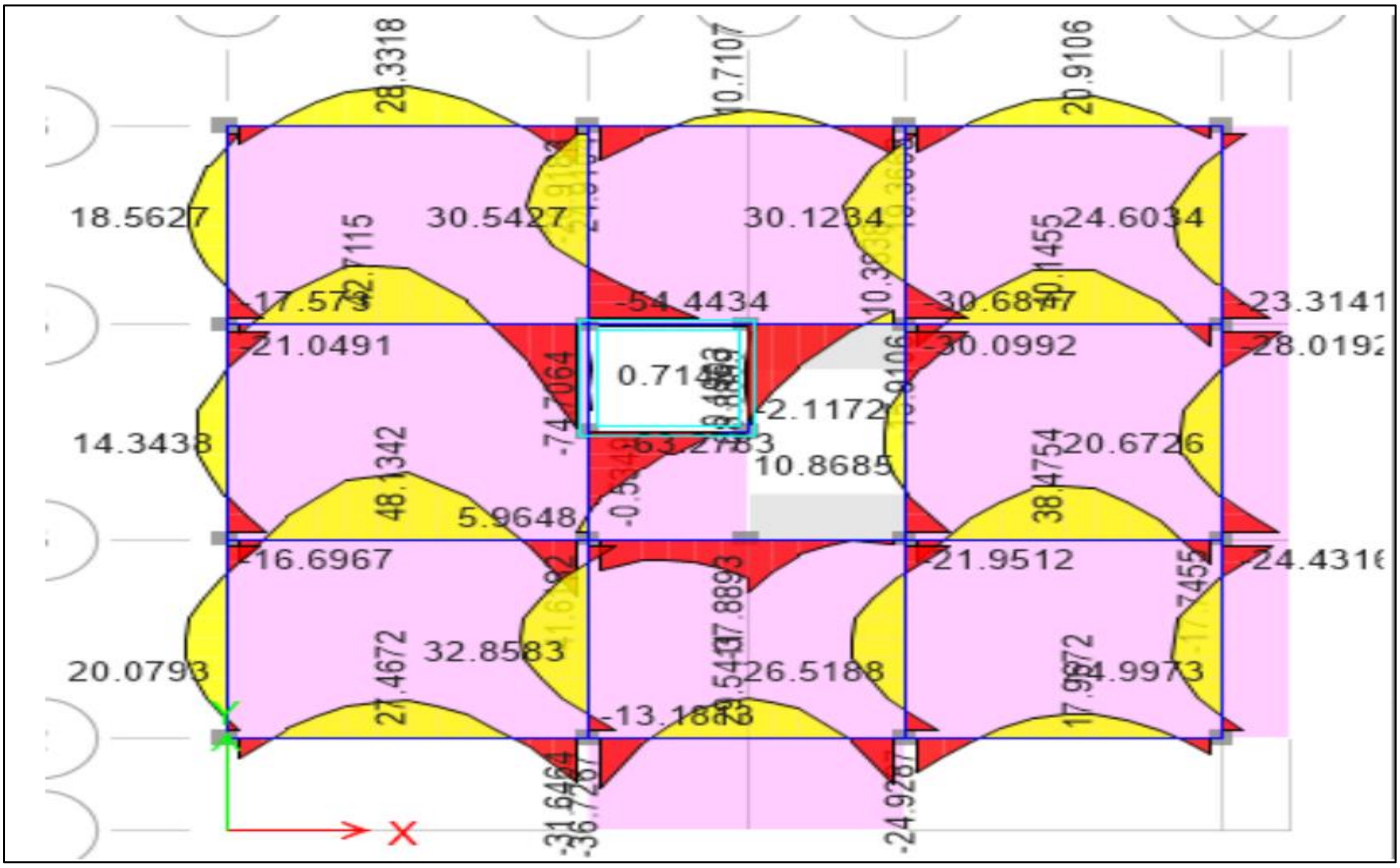


Fig 3 Deflection due to Bending Moment for RCC Structure

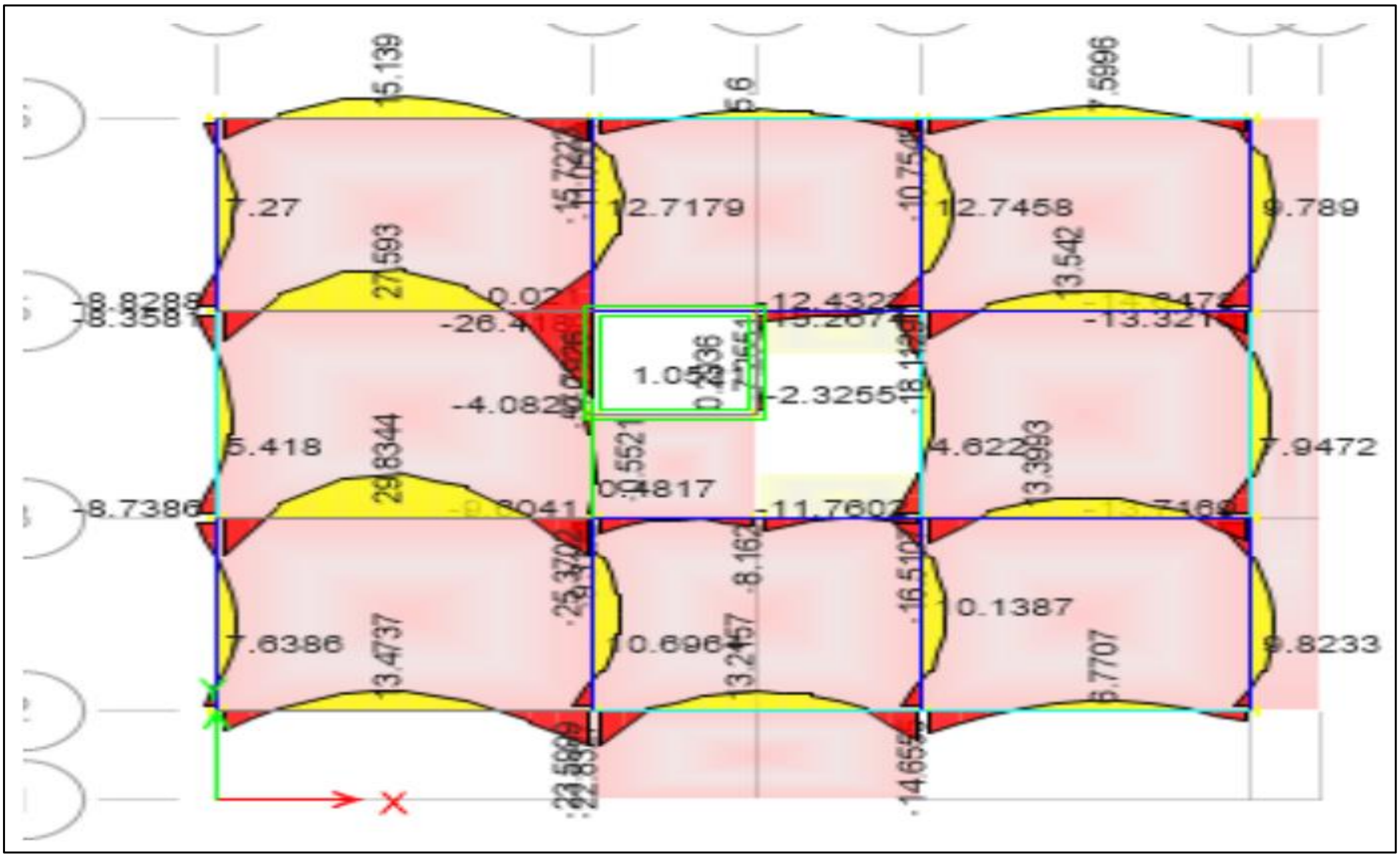
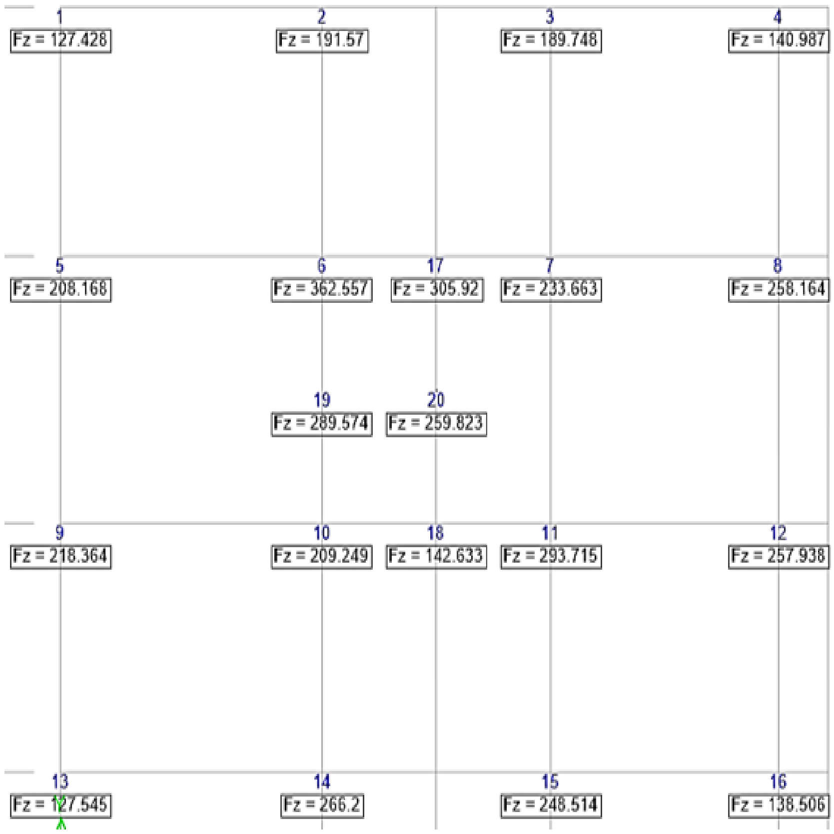


Fig 4 Deflection due to Bending Moment for STEEL Structure

➢ *Base Shear & Foundation*



RCC Structure		
Points	Base Reactions (Kip)	Footing Area[ft2]
1	127.43	42.48
2	191.57	63.86
3	189.75	63.25
4	140.99	47.00
5	208.17	69.39
6	362.58	120.86
7	233.66	77.89
8	258.16	86.05
9	218.36	72.79
10	209.25	69.75
11	293.71	97.90
12	257.94	85.98
13	127.54	42.51
14	266.20	88.73
15	248.51	82.84
16	238.51	79.50
17	305.92	101.97
18	142.63	47.54
19	289.57	96.52
20	259.82	86.61

Fig 5 Base Shear/Loads at Foundation of RCC Structure

STEEL Structure		
Points	Base Reactions (Kip)	Footing Area[ft2]
5	58.90	19.63
6	112.40	37.47
8	107.04	35.68
9	73.63	24.54
10	127.73	42.58
1	298.59	99.53
11	173.64	57.88
12	176.49	58.83
13	134.10	44.70
14	163.70	54.57
16	223.28	74.43
17	175.45	58.48
18	57.56	19.19
19	180.30	60.10
21	166.36	55.45
22	71.97	23.99
2	223.80	74.60
15	78.58	26.19
3	218.48	72.83
4	164.03	54.68

Fig 6 Base Shear/Loads at Foundation of STEEL Structure

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Figure 05 and Figure 06 displays the vertical base shears for both of the structures. The vertical shears for RCC structures imposing massive loads compare to STEEL and which affects a lot to the requirements of foundation design and costs. Maximum base shear for RCC Fz(max)=362.58 and the footing (362.557+36.2557)/3=124.629 sq.in, For STEEL structure Fz=296.557 and the footing (296.557+29.6557)/3=101.95 sq.ft . Corner footing loads for RCC [at point 1] Fz=127.428 K and for STEEL [at point 5] Fz=58.948 K. So, 127.428-58.948=64.48 K considering 3 ksf allowable pressure of soil requirements of additional foundation area for RCC structure 64.48/3=22.827 sq.ft , loads for RCC [at point 4] Fz=140.987 K and for STEEL [at point 9] Fz=73.711 K. So, 140.827-73.711=67.276 K, requirements of additional foundation area for RCC structure 67.276/3=22.4254 sq.ft .Therefore the RCC structure demands larger foundation areas due to higher base shear forces, leading to increased foundation costs compared to the Steel structure. This additional area requirement can significantly drive up the overall construction costs for RCC structures, especially when high base shears are involved.

Figure 03 and Figure 04 displays the difference of deflection in beams and joints while steel frames are spectating almost 35-40% reduced deflection compare to RCC and it observed because of inferior self-weight or dead loads.

➢ *Lateral Load*

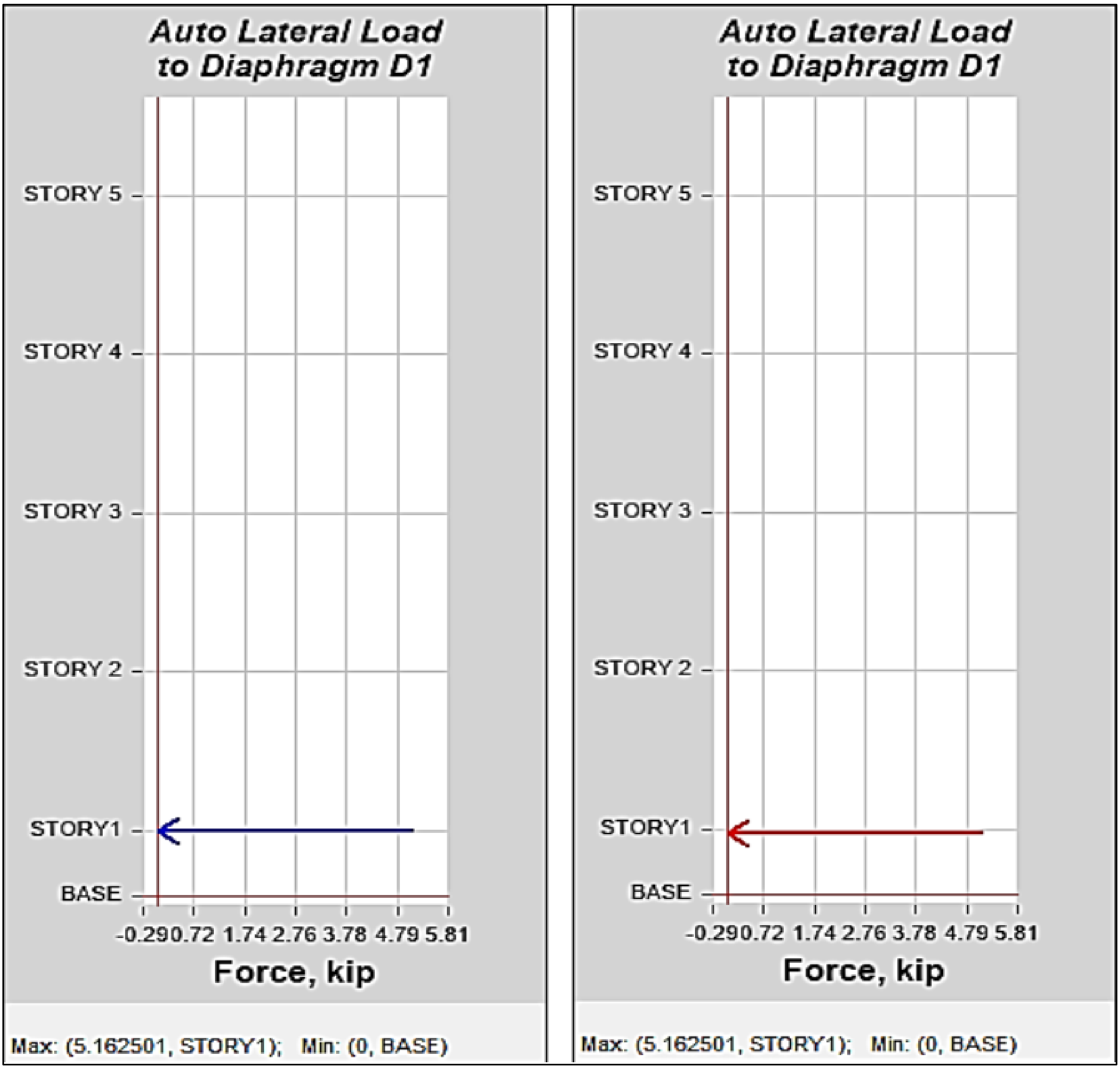

Fig 7 Auto Lateral Loads in x and y Direction STEEL Structure due to Earth Quake Effect.

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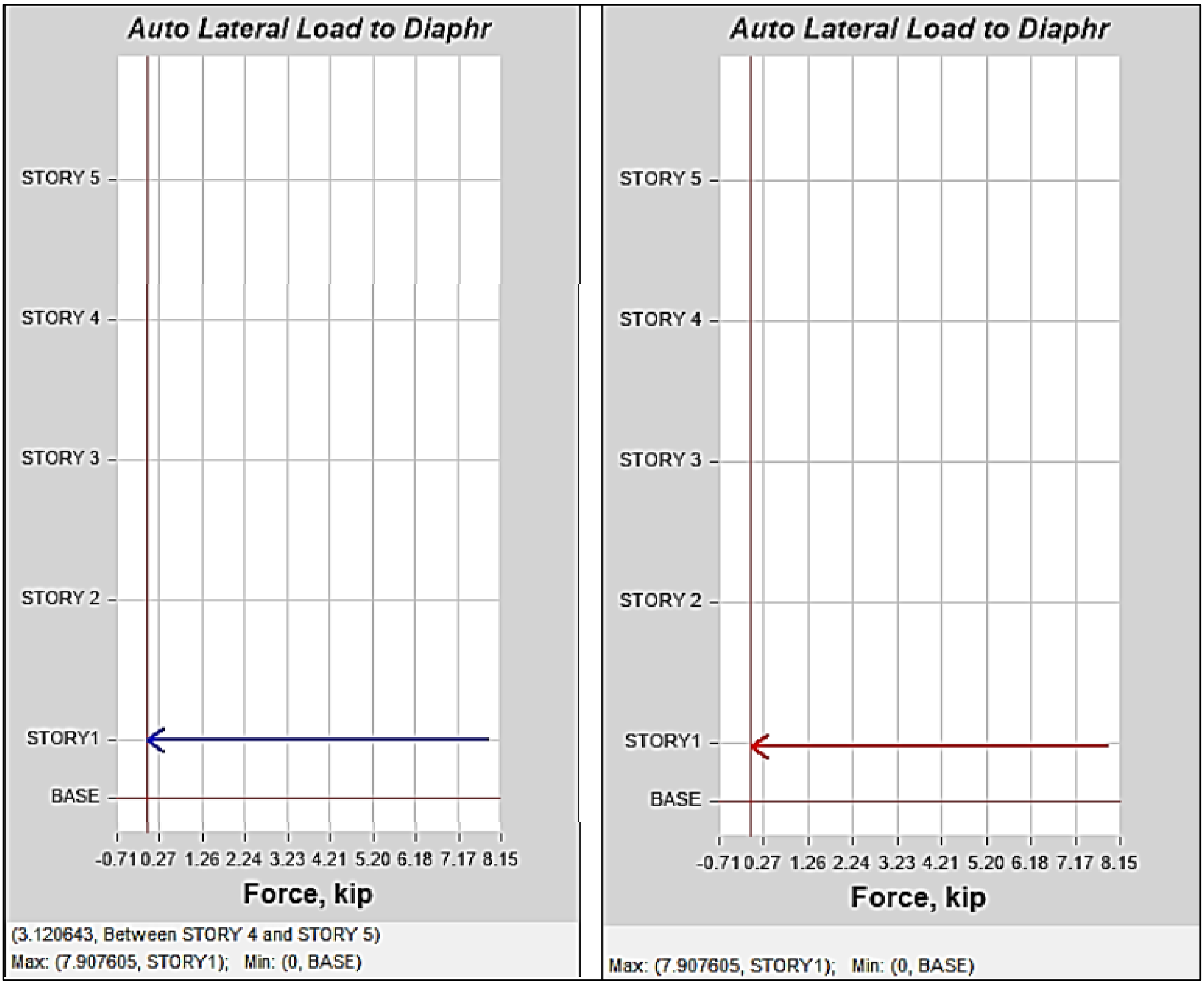

Fig 8 Auto Lateral Loads in x and y Direction RCC Structure due to Earth Quake Effect.

After analyzing the stiffness curve from ETABS its safe for both of the structure and Figure: 07 & Figure: 08 shows the auto lateral loads/earthquake loads which are generating 5.16 k for STEEL structure and 9.07 k for RCC structure generates from the assigned loads and self-weight of the structure. Report for maximum story displacement is about 1.64 inch in x direction and 1.57 inch in y direction and for RCC structure 1.4 inch in x direction and 1.3 inch in y direction. Though the story displacement ratio of steel structure is slightly high due to the reduced vertical shear from dead loads but steel is severely ductile martial and the ratio is almost 180 times compare to concrete. So, here is no chances of deformation for steel structure and it will easily exceed concrete structure in seismic test.

II. CONCLUSION

The findings from this study highlights necessary benefits of steel framing system compare to worldwide popular reinforced concrete structures. Now a days manufacturing process of concrete martials has been threatening the environment majorly and the Environmental Engineers are working really hard to reduce the pollution through different EIA management process but they are not managed to stop this. Also, it is more resilient to withstand against lateral loads like earthquake and wind pressures.

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