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| RESEARCH ARTICLE

Analysis and Construction Process of a Multi-Storey Steel Office Building

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| ABSTRACT

This research paper explains with a certain amount of detail the whole process involved in the design of a Multi-storied steel construction, from the preliminary architectural design to the final structural detailed drawings. As specified in the project description, structural steel has been quite popular for the past 30 years, it's been fruitful to experience the efficiency of the structural steel properties during the design process and achievement. To accomplish this design, we mainly used licensed software by Autodesk, including Revit Structures for the architectural design and Robot Structural Analysis Professional for the structural analysis and design. The analysis shown that Steel's ductility allows it to withstand significant deformation before breaking. Steel-framed buildings' ductility allows them to disperse energy from earthquake-induced building movement, reducing structural damage. Hence, it would be a sustainable construction process when adequate structural steel in the building especially for the multi-storied building cases.

| KEYWORDS

Steel Structure, Steel quality, Multi-layer Building; Architectural & Structural Design, Structural Analysis.

| ARTICLE INFORMATION

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1. Introduction

Multi-storey steel frame structures consist of beams and columns made from welded H-shaped steel or hot-rolled H-shaped steel, designed to handle gravity loads such as dead and live loads. These structures are commonly used in residential, commercial, and institutional buildings worldwide due to their high strength-to-weight ratio, ability to accommodate large spans and lightweight construction, and the ability to have various structural forms like braced and moment-resistant frames (Ahmed & Sobuz, 2011; Akid, Shah, et al., 2021; Akid, Wasiew, et al., 2021). Steel frames are faster to erect than reinforced concrete frames, resulting in economies. They are prefabricated in the factory under effective quality control, making subsequent alterations or strengthening easier. Steel frames are also more suitable to withstand lateral loads caused by wind or earthquake (Rahman & Sobuz, 2018). Multi-storey buildings are typically composed of multiple floors, stairs, lifts, and ramps (Hasan et al., 2011). They require careful considerations such as fire safety, light, maintenance, evacuation, and cleaning. There are different types of multi-storey buildings, including low-rise buildings, mid-rise buildings, high-rise buildings, skyscrapers, supertall buildings, and mega tall buildings (Rackauskaite et al., 2017). Builders follow a series of steps to create a multi-storey building, including the design process, foundation, casting the columns, and checking the beam bottom and slabs. The design process usually involves using software or programs to ensure safety and feasibility, with licensed professionals designing formwork, staircase design, slabs, and deep beams (Jing et al., 2020).
Foundation is crucial for handling most of the lateral weight of the building, and excavation is necessary. The surface is then "dressed" or leveled, and PCC is poured over it before foundations and columns are laid out. Casting the columns involves using link bars and column ties, which depend on the size of the structure (Kumar et al., 2019). An L bar is used to displace the main bars, and contractors must check the height of the cast and formwork plumb. Multi-level steel buildings work similarly to single-storey buildings, ensuring flexibility and stability (Ahmed & Sobuz, 2011; Gorgun & Karamis, 2019). The process depends on ground

conditions, with higher wind loading increasing the price per floor area. Steel is the most suitable material for providing stability to multi-level buildings, as it prevents frame sway and provides resistance to torsional and lateral loads

Steel structures are metal structures made of steel components that are structurally interconnected to carry loads and provide full rigidity. These structures have unique properties, such as being corrosion-resistant, durable, and thin, making them suitable for construction. As the construction industry shifts towards sustainable development, steel structures offer new opportunities for cost savings. The development of steel construction has led to rapid changes in the use of wood, as mild steel can shorten processing time and improve structural performance. The efficiency of steel construction is significant, with examples like the steel-concrete hybrid frame framework in Raffles City Chongqing. This system combines the steel frame and concrete outrigger walls, reducing construction time and material costs. The steel construction industry is crucial for achieving community goals and reducing costs (Ayebeng Botchway & Afful, 2018).

Steel is a popular choice for earthquake-resistant structures due to its strength, durability, non-combustibility, flexibility, and durability. Its high strength-to-weight ratio allows it to support a lot of weight while remaining relatively light, reducing seismic forces (Sharma et al., 2014). Steel can deform significantly before breaking, absorbing energy from earthquakes. It is non-combustible, reducing the risk of fire. Steel can bend without breaking, allowing buildings to sway safely during an earthquake. It can endure the initial impact of an earthquake and maintain its shape over time. Techniques for improving steel structures include steel frame systems, high strength low alloyed (HSLA) steels, and cross bracing, which keeps buildings stable during earthquakes and limits lateral movement. Although earthquakes are uncontrollable natural occurrences, their effects can be lessened. The primary impacts of earthquakes on civil engineering structures are reviewed in this study along with potential mitigation strategies to lessen seismic vulnerability. The primary elements examined are the liquefaction of tunnels and dams, the tilting and cracking of buildings and roads, and the effects of scour depth and live load on bridges. Through observations of recent large earthquakes, the primary causes of earthquakes and their effects on civil engineering structures are examined (Carson, 2016).

High-quality steel is a crucial material in modern construction due to its strength, lightweightness, and ease of use. It offers numerous benefits, including increased durability and resilience (Sobuz et al., 2023; Uddin et al., 2013). Steel is suitable for various projects due to its predictable qualities, allowing fabricators and designers to meet tight tolerances (ERIKSSON & Andersson, 2016). The in-house quality control initiatives at steel buildings ensure the desired outcome. Premium steel is preferred by architects and builders due to its exceptional strength and structural integrity. Its strength-to-weight ratio allows for stronger and lighter structures. Steel also resists harsh weather, seismic activity, and other external influences, providing residents with a sense of security and comfort. High-quality steel is essential for building construction due to its predictable qualities, ability to meet tight tolerances, and exceptional strength. Its in-house quality control initiatives ensure the desired outcome and its natural strength makes it a preferred choice for architects and builders (Navyashree & Sahana, 2014).

Mild steel has a minimum strength of G550, a minimum melting strength of 550 MPa, and a shear modulus of 80,000 MPa, and an elastic modulus of 200,000 MPa. Light Steel Framed construction (LSF) reduces demand during various stages of the building's cycle, contributing to a more sustainable built environment. Through numerical engineering, steel construction can minimize costs and be highly effective(Jing et al., 2020). Additive Manufacturing is crucial for producing metallic structural elements for civil engineering applications. However, there is limited knowledge about the structural response of Wire-and-Arc Additive Manufactured (WAAM) metallic elements. A study at the University of Bologna's Topography and Structural Engineering Labs assessed the geometrical and mechanical properties of WAAM stainless steel (Laghi et al., 2020). Surface irregularities and evaluated the material's mechanical properties, including tensile and compressive strengths, Young's modulus, and post-elastic behavior. The results were interpreted using statistical tools to determine mean values and variability of geometrical and mechanical parameters (Laghi et al., 2020; Zhang et al., 2019).

Given how quickly technology is developing, we are living in a truly amazing time (Carson, 2016). Whereas it used to take months to fully design and analyze a multi-story building, today the process can be finished in a matter of hours with the right information, producing incredibly accurate results. Since steel is a fantastic material that has been used for a long time, the design and analysis process must be done in the field of civil engineering (Densley Tingley et al., 2017). Throughout the process, one can acquire experience handling the various and adaptable qualities of steel, which require careful control. Buckling, fire, and a host of other factors can affect how well steel performs. With just a few clicks, we can check and analyze the entire structure while saving a significant amount of time by using specialized software like Autodesk Robot and Revit. In this thesis paper, the entire process of designing a multi-layer steel structure from the initial architectural design to the final structural detailed drawings is explained in some detail.

2. Literature review

The use of stainless steel in buildings has increased due to its corrosion properties and long service life. Ferritic and lean duplex grades, with low nickel content, are more cost-stable and economic than austenitic stainless steels. These grades have comparable strength to carbon steel and good corrosion resistance at lower costs. This paper discusses the advantages of stainless steel in recent construction projects and introduces the new European standard EN 15804, which allows credits for future reuse or recycling of material at the end-of-life stage. It also presents life cycle inventories of stainless steel products and potential impacts for four grades: austenitic, ferritic, and duplex (Rossi, 2014). The UK construction industry faces declining levels of structural steel reuse, according to a study by Sansom and Avery (2014). The study identified five significant barriers to structural steel reuse: cost, availability/storage, no client demand, traceability, and supply chain gaps/lack of integration. These barriers contrast with those commonly identified in global literature, which focus on technical barriers (Al Nageim, 2016). To increase reuse rates, a coordinated approach across the UK construction supply chain is needed. The paper proposes four mechanisms to overcome these systemic barriers: creating a database of suppliers/reused section availability, demonstrating client demand, providing technical guidance and education, and implementing government leadership. These measures would improve reuse rates, reduce embodied emissions, and contribute to meeting greenhouse gas emission targets (Densley Tingley et al., 2017).

The steel industry heavily relies on logistics for storage and movement of work in process (WIP) materials, with thousands of tons transported daily. The industry's pressure to reduce costs significantly influences logistics operations, with efficiency being a crucial factor. This article focuses on slab logistics, specifically performance measurement, quality assurance, and operational control in processes following continuous caster. It evaluates performance measurement and demonstrates how quality assurance can be supported. Prescriptive analytics methods are employed to automate or support human resources in handling complex logistics operations (Beham et al., 2020). High-carbon steel wires are crucial for bridge cables, tire reinforcement materials, and photovoltaic industry cutting materials. Poor control of centerline segregation, inclusion, and microstructure can negatively impact drawability and fatigue performance. Prof. Weiqing Chen's group at UTSB has been researching quality control of high-carbon steel using a low-cost one-stage hot rolling process since 2000. The research includes intensive secondary cooling, final electromagnetic stirring, final permanent magnetic stirring, soft reduction, and a combination of redesign of submerged entry nozzle, refining slag, Al-free refractory, and low-melting-point compounds. Research has been applied in over 10 steelworks and expanded to spring steel, welding wire steel, and wire rods (Yan et al., 2019).

A study investigates the bending properties of a new thermomechanically processed medium-carbon low-alloy steel for slurry transportation pipeline applications. The material was hot-rolled into 10mm thick strips and quenched at different temperatures (560 and 420°C). The samples were cooled to room temperature, producing two different biotitic microstructures. The study found that the higher-temperature biotitic sample had almost equal amounts of bainite types B1 and B2, with B1 having low dislocation density and intralath cementite, and B2 having a very dislocation-dense morphology with mainly interfaith cementite (Kaijalainen et al., 2019). The QST 420 sample had high dislocation density components B2 bainite and martensitic, with martensitic only present near strip surfaces. Different post-rolling cooling conditions slightly increased the texture intensity of the QST 420 sample. The QST 560 sample had higher elongation to fracture and work-hardening capacity, resulting in a smaller minimum usable punch radius (Javaheri et al., 2020). Packaging steel's high-quality performance is crucial for its flatness, tension-free surfaces, and resistance to spring back. The stretch-bending process at the final stage ensures these parameters. However, plastic deformation can alter mechanical properties due to different process parameters. This study develops a multivariate predictive model to calculate the process window for achieving desired flatness and mechanical properties in packaging steel production, validated through laboratory experiments.

Modular construction offers faster, safer, and more environmentally friendly solutions than traditional methods. However, the private sector still heavily relies on traditional on-site construction. Modular buildings are widely used for low-rise buildings and multi-storey structures. They offer satisfactory performance under various conditions and offer environmental, economic, and social benefits. The acceptance of modular construction will increase with design guidelines, skilled workers, and innovative interlocking connections. Composite materials have shown high potential for manufacturing prefabricated building modules. In Australia, modular construction is expected to increase from 3% to 5-10% by 2030 (Ferdous et al., 2019). Modular timber construction is a pioneering and eco-friendly method in the building sector, offering structural advantages and a reduced carbon footprint compared to conventional materials like concrete, masonry, and steel. This work explores contemporary modular construction using wood as the primary material, focusing on fundamentals of modularity, layout design, structural systems, stability, inter-module joining techniques, MEP integration, and disassembly designs. Timber modular construction, inspired by steel modular concepts, consistently uses linear members with stability configurations and diverse joint techniques. Despite modularization and prefabrication, many solutions still focus on on-site linear assembly. Timber structures typically have rectilinear, symmetric plans with regular and repetitive extrusions, demonstrating a proclivity for centrally located cores. This study aims to provide insights into the current utilization of modular timber construction and identify gaps for exploration, enabling the advancement of modular timber projects and systems.

The steel industry is experiencing significant growth in global nations and Gulf countries, and Iraq should be one of the leading nations in developing its construction industry. The government should prioritize the steel industry and provide full support to the general sector, including the Ministry of Industry and its institutions. A study aims to use scrap steel as raw materials for manufacturing iron steel, such as war remains, tanks, and broken trucks, and to construct new plants and reconstruct old ones, as seen in the Khor al-Zubair factory in Basrah (Hosseini Hashemi & Keykhosro Kiany, 2018). Iron is considered indispensable in engineering applications due to its low cost and strength, and is classified as its purity and alloy component availability. Pig iron, containing 3.5-4.5% carbon and impurities like sulfur, silicon, and phosphorous, is a middle step in producing cast iron and steel iron. The research aims to develop a development mechanism to reopen iron factories in Iraq, reshaping the construction industry without importing steel from other countries and focusing on horizontal expansion to export steel iron after meeting local market needs. Pallet racks, used for industrial and commercial activities, have seen improvements in seismic load provisions. However, there are still areas for improvement, such as seismic isolation systems. Current European and American standards lack guidance on these systems. Two methods to enhance rack performance in seismic zones are rack netting and structural strengthening, which pose logistic and technical challenges (Simoncelli et al., 2020). Researchers are exploring base isolation systems to reduce structural damage and improve safety. Avoiding overturning of merchandise is crucial, as the cost of the structural frame is often negligible. This paper presents a critical overview of base isolation systems for different steel storage rack typologies, discussing their main characteristics and practical applications.

Steel slag, a by-product from the steelmaking process, is a significant environmental and resource-intensive waste. Its direct use poses significant risks to the mechanical properties and durability of composites. However, recent research has shown that accelerated carbonation can improve the properties of steel slag. This review discusses various types of steel slags and their chemical/mineral compositions and highlights recent progress in using accelerated carbonation to enhance steel slag quality (Rackauskaite et al., 2017). The challenge lies in understanding the interconnectedness of influencing factors and their relative contributions to property improvement. The review also introduces practical applications of carbonated steel slag with improved properties and provides insights into the challenges of using accelerated carbonation for future research and industrial applications (Karlsson et al., 2020). The building sector is crucial in reducing global energy consumption, with stricter regulations for thermo technical design. The redefined nearly Zero Energy Building levels will force designers to rethink their designs to achieve mandatory levels without increasing construction costs. A steel-framed building in Romania was assessed for its thermo-energy performance in a moderate continental temperate climate (Deng et al., 2020). The study found that the building's thermal performance, adjusted thermal resistances, and global thermal insulation coefficient were all in compliance with Romanian regulations. The research suggests that emphasis should be placed on the thermotechnical design of Light Steel Framed solutions to achieve nZEB levels. Although the results show exemplary behavior compared to classical solutions, iterative redesign is needed to achieve all thermo-energy performance indicators (Bienert, 2018).

3. Martials and Methodology

Three components comprise the entire methodology the structure philosophy, the structure description, and design process. The structural philosophy is based on a modern philosophy that incorporates elements of traditional architectural design. The J building on the China Three Gorges University campus, which houses both an office and a teaching building, served as a major inspiration for the room arrangement and space management. Appropriate framework that effectively laid a solid foundation for our upcoming "structural design" project while also meeting the functional requirements of an office and teaching building, which is our goal.

Figure 1: inspired model.

Figure 1 shows an inspired model of a building. The building is composed of offices and a teaching building, which is primarily composed of classrooms. The J building on the campus of Three Gorges University in China served as the primary inspiration for the structure. The preliminary design was the first stage of the design process, during which I had to consider the future building's shape, the functions of the rooms, the building orientation, the number of buildings, and every other detail. It delivered the structure's initial appearance using hand-drawn sketches. After that, the design specifications and Chinese codes about steel structures must be followed when detailing. After being mastered in AutoCAD, the architectural and structural drawings will be exported to dwg format.

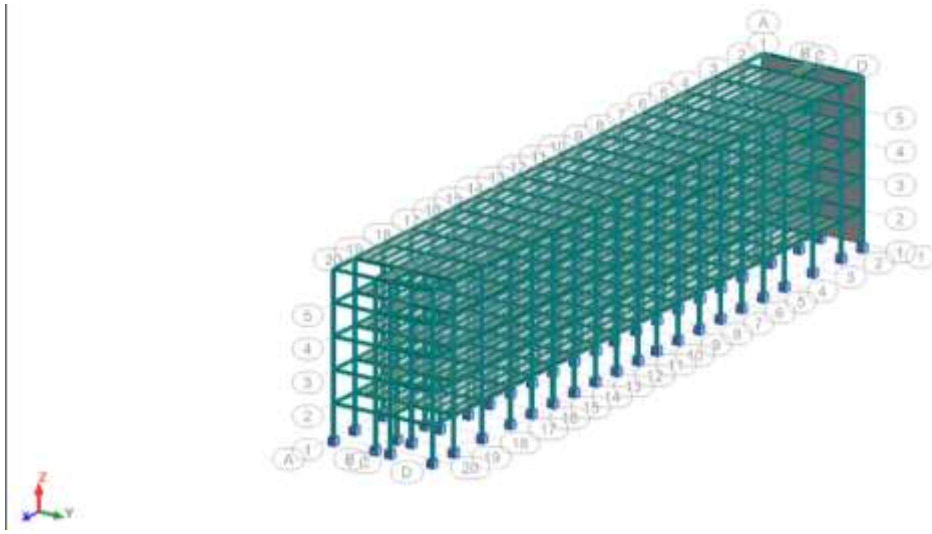


Figure 2: Autodesk Revit User interface.

Figure 2 shows an Autodesk Revit User interface. For effective BIM design, the Autodesk Revit User interface includes a ribbon, properties palette, project browser and drawing area.

4. Result and Discussion

The structural design and analysis process involves transferring architectural designs from Autodesk Revit to Autodesk Robot, transforming the structure into an analyzable frame. Different load cases are applied to assumed structural members, and load combinations are generated automatically according to the Chinese code. The software shows detailed reports on adverse situations for each member, allowing for corrections and calculations until every member is safe. The design of connections, including beam-to-beam and beam-to-column connections, and RC members like slabs, stairs, and foundation are designed. The Structural members: columns, girders, and beams also shown in Figure 3. Reinforcements are provided based on load combinations, and reports are generated. The seismic analysis is modal, based on the Chinese code, with a minimum of 90% mass participation for structure safety.

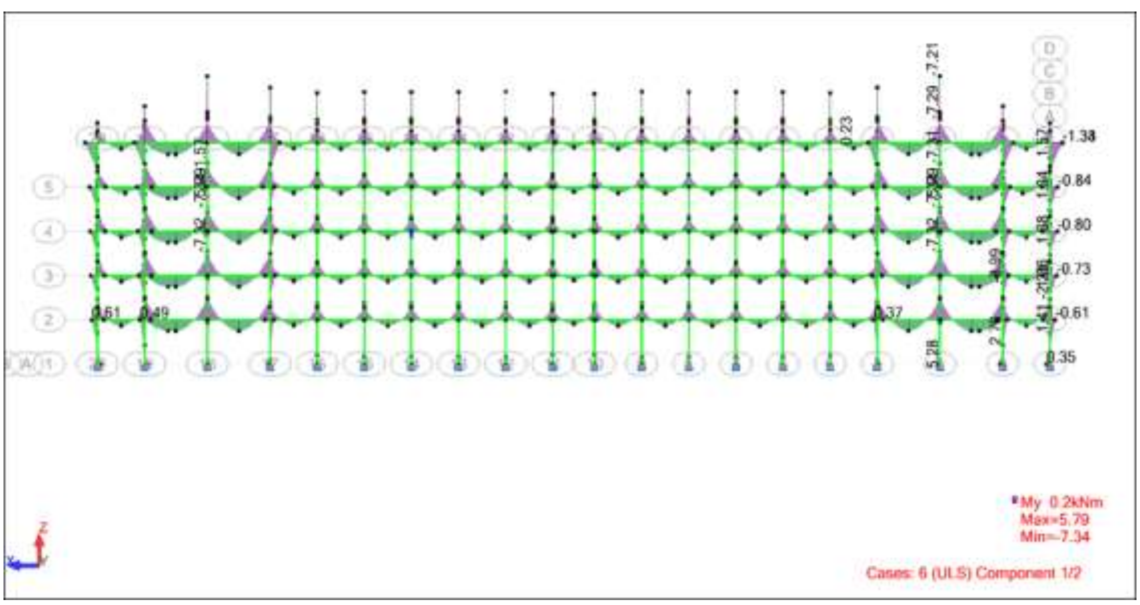


Figure 3: Structural members: columns, girders, and beams.

The selection data for different steel materials are examined and tabled in the following tables.

Table 1. Selection data.

Section name	Bar list	AX (cm2)	AY (cm2)
H 350x300x0	37to54 58to65 67to98 264to289 291to322 373t-o398 400to431 499to509	98.10	72.00
I 33	135to137 139to141 144to146 148to150 152to15-4 156to158 160to191 323to372 432to481	53.80	31.36
HW 400x1	1to36 192to263 491to498	197.80	144.00

Table 1 shows the selection data for different steel materials.

Table 2. Selection properties.

Section name	AZ (cm2)	IX (cm4)	IY (cm4)	IZ (cm4)
H 350x300x0	28.00	40.12	22880.00	5400.00
I 33	23.10	16.63	9840.00	419.00
HW 400x1	54.00	305.35	57678.00	10817.00

Table 2 shows the selection properties for different steel materials.

Table 3. Materials data.

	Material	E (MPa)	G (MPa)	NI	LX (1/°C)	RO (kN/m3)	Re (MPa)
1	Q235	206000.00	79000.00	0.30	0.00	77.01	215.00
2	Q345	206000.00	79000.00	0.30	0.00	77.01	310.00
3	STEEL	206000.00	79000.00	0.30	0.00	77.01	215.00

Table 3 shows the data for different steel materials.

Table 4. Load case.

Case	Nature	Analysis type
1	dead	Static - Linear
2	dead	Static - Linear
3	Live 1	Static - Linear
4	Live 1	Static - Linear
5	wind	Static - Linear
6	Snow I	Static - Linear
7		Static - Linear

8		Static - Linear
9		Static - Linear
10		Static - Linear
11		Static - Linear
12		Static - Linear

Table 4 shows the Load case for different steel materials.

Table 5. Load values.

Case	Load type	List	Load values
1	self-weight	1to54 58to65 67to98 135to137 139to141 144to146 148to150 152to154 156to158 160to289 291to398 40-0to481 491to509 511to516	PZ Negative Factor=1.00
2	(FE) uniform	511to515	PZ=-10.00(kN/m2)
3	(FE) uniform	511	PZ=-2.00(kN/m2)
4	(FE) uniform	512	PZ=-2.00(kN/m2)
5	(FE) uniform	516	PX=0.35(kN/m2)
6	(FE) uniform	513to515	PZ=-0.40(kN/m2)

Table 5 shows the Load case for different steel materials.

After the initial selection and load testing, the quality analysis is done as a background check and the data gained from the test is shown in the following tables.

Table 6. Quality survey.

Type	Number	Length (m)	Unit weight (kG/m)	Bar weight (kG)	Total weight (kG)	Painting area (m2)
Q235						
H 350x250x0	27	3.00	77.04	231.11	6240	152.60
H 350x250x0	14	3.30	77.04	254.22	3559	87.04
H 350x250x0	48	3.50	77.04	269.63	12942	316.51
H 350x250x0	39	5.00	77.04	385.18	15022	367.38
H 350x250x0	14	5.30	77.04	408.29	5716	139.79
H 350x250x0	31	5.94	77.04	457.60	14185	346.92
H 350x250x0	12	6.00	77.04	462.22	5547	135.65
HW 400x1	80	3.50	155.33	543.65	43492	539.45
HW 400x1	36	4.00	155.33	621.32	22367	277.43
I 28	12	3.30	42.25	139.42	1673	46.37
I 28	84	3.50	42.25	147.87	12421	344.27
I 28	21	5.00	42.25	211.24	4436	122.95
I 28	12	5.30	42.25	223.92	2687	74.48
I 28	21	6.00	42.25	253.49	5323	147.55
Total per sections						

H 350x250x0	185	820.54	77.04	63211.37	63211	1545.90
HW 400x1	116	424.00	155.33	65859.52	65860	816.88
I 28	150	628.20	42.25	26540.35	26540	735.62
Total					155611	3098.40

Table 6 shows the Quality survey for different materials.

Satisfied with the steel design, several beam-to-beam and beam-to-column connections as structural connections were conducted which landed in several confirmations for resistance, shear, bending, flange, web compression, and other partial safety factors. Beam-to-beam and beam-to-column connection proposals are depicted in the following images of Figure 4(a) and 4(b).

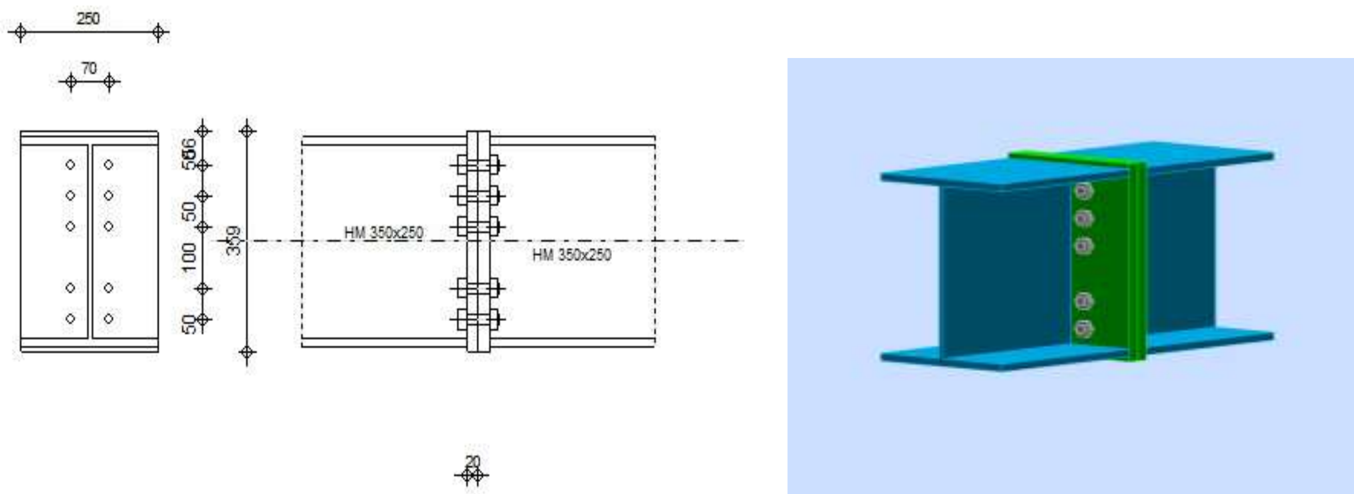
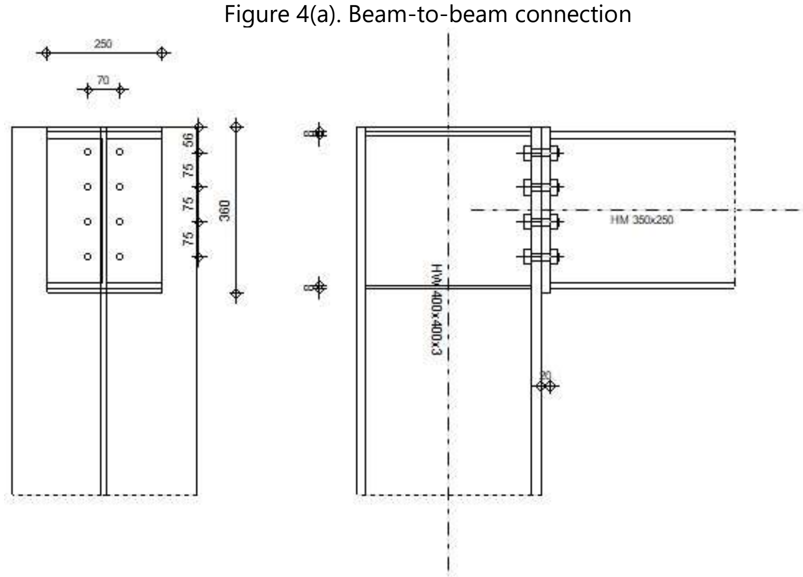


Figure 4(a). Beam-to-beam connection



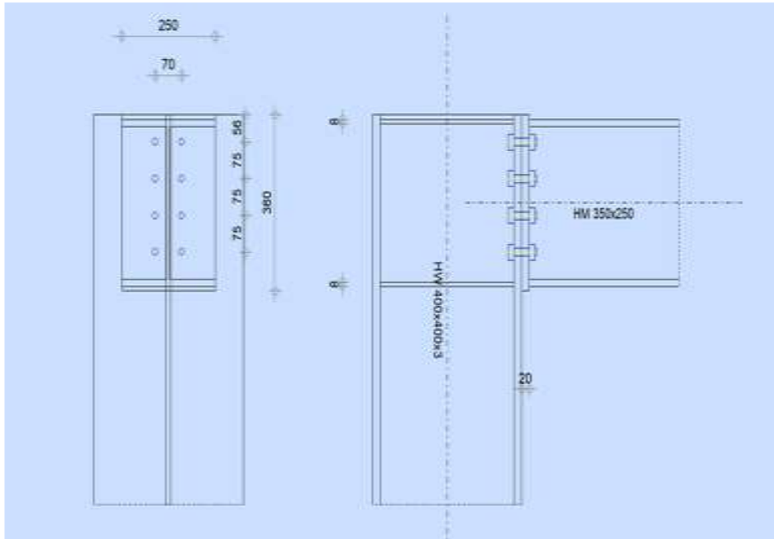


Figure 4(b). Beam to column connection.

The beam-to-beam and beam-to-column connection strength is a must for building strength. The higher the bond the more earthquake-proof the building is. A table for dynamic analysis for several case combinations and periods for earthquake frequency is given below.

Table 7. dynamic analysis.

Case/Mode	Frequency (Hz)	Period (sec)	Rel.mas.UX (%)	Rel.mas.UY (%)
13/ 1	4.13	0.24	95.49	0.01
13/ 2	4.40	0.23	95.63	71.01
13/ 3	4.57	0.22	96.66	75.62
13/ 4	5.46	0.18	96.72	76.63
13/ 5	5.69	0.18	96.97	76.70
13/ 6	6.35	0.16	96.98	77.16
13/ 7	7.97	0.13	97.13	77.18
13/ 8	8.11	0.12	97.14	77.83
13/ 9	9.22	0.11	97.15	77.87
13/ 10	11.26	0.09	97.15	79.49
13/ 11	11.81	0.08	97.15	81.93
13/ 12	11.99	0.08	97.15	82.26
13/ 13	12.42	0.08	97.16	82.29
13/ 14	13.51	0.07	98.65	82.31
14/ 1	4.13	0.24	95.49	0.01
14/ 2	4.40	0.23	95.63	71.01
14/ 3	4.57	0.22	96.66	75.62
14/ 4	5.46	0.18	96.72	76.63
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14/ 10	11.26	0.09	97.15	79.49
14/ 11	11.81	0.08	97.15	81.93
14/ 12	11.99	0.08	97.15	82.26
14/ 13	12.42	0.08	97.16	82.29

14/ 14	13.51	0.07	98.65	82.31
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16/ 9	9.22	0.11	97.15	77.87
16/ 10	11.26	0.09	97.15	79.49
16/ 11	11.81	0.08	97.15	81.93
16/ 12	11.99	0.08	97.15	82.26
16/ 13	12.42	0.08	97.16	82.29
16/ 14	13.51	0.07	98.65	82.31

Table 7 shows the dynamic analysis for several case combinations and periods for earthquake.

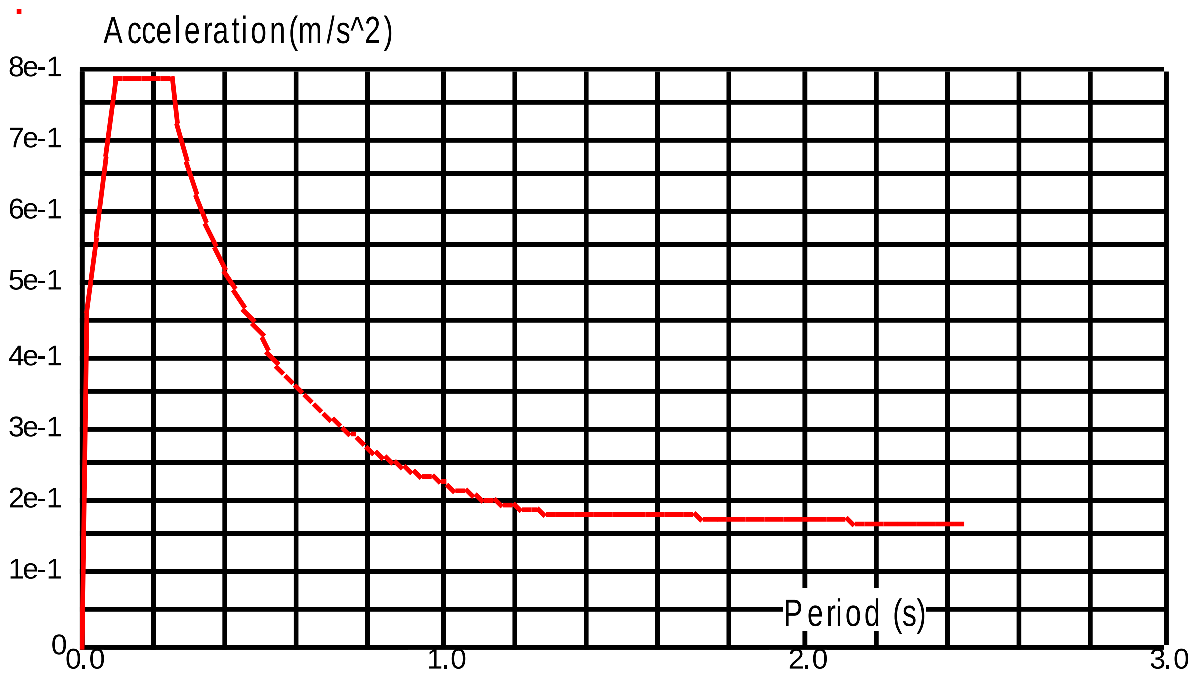

Figure 5. generalized graph for testing steel resistance against steel.

Several acceleration to time curves regarding the earthquake for the steel to endure is tested. A generalized graph is shown in Figure 5. After all the tests and considerations, it can be said that the Structure response to earthquakes is encouraging.

5. Conclusion

This paper presents the analysis and construction effectiveness of structural steel in the muti-storied building projects. The construction sector is transitioning to practical and cost-effective structural materials, such as transition steel construction, to reduce unbalanced wood use and meet the growing steel demand, particularly in Chinese-style buildings. Because of its ductile nature, steel can undergo substantial deformation before breaking. Because of their ductility, steel-framed buildings can dissipate the energy from earthquake-induced building movement, lessening the damage to the structure's integrity. Hence, the adequate structural steel can be incorporated in the muti-storied building construction for the sustainable development in civil construction industry in the world. It would be a great insight when appropriate construction method adopt in the structural multi-storied building construction to avoid unnecessary delays of the construction process especially for the multi-storied building.

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