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SEISMIC EFFECT ON THE MICADO STRUCTURAL SOLUTION. A NUMERICAL ANALYSIS.

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Abstract

MICADO is a modular construction system for dwellings, proposed and developed by a Portuguese construction startup. In brief, it consists of building the dwelling envelope using prefabricated panels. The panels come pre-finished and include adequate thermal insulation. They have a width range between 300 mm to 1200 mm. Each panel is vertically perforated to assist with its on-site assemblage, and accommodate the structural components. The solution allows a wide range of architectural solutions, as well as multiple size openings (e.g., doors and windows). The present paper aims to propose a structural solution for the MICADO construction system. Considering the modular building requirement and using prefabricated panels, assembling a particular type of column-to-beam connections and structural behavior under gravity and seismic loads should be investigated. The structural solution is formed by steel pipe, box, and L-shaped prefabricated profile columns, steel H-shaped pro-file beams, and a steel-deck composite floor. The panels are assembled in the steel profile columns. For this purpose, a two-floor MICADO dwelling is analyzed and designed using numerical modeling, and the structural performance is evaluated. The results show valuable insights into the design and construction of the MICADO method as a steel-based modular structure.

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1 INTRODUCTION

Modular structure or construction is an innovative approach that has recently gained popularity. This method involves the use of prefabricated building components or modules that are manufactured off-site and then assembled on-site to create larger structures. This approach offers a range of benefits over traditional construction methods, including faster construction times, improved quality control, and increased sustainability [1–3]. Modular construction has been applied to various building types, including residential homes, commercial buildings, and schools [4]. As the demand for faster, more efficient construction methods continues to grow, modular construction is likely to become an increasingly important technique for meeting the needs of the building industry.

There are varied types of modular construction, such as steel-, concrete-, and wood-based materials [5–7]. However, research has focused more on case studies and aimed at developing and solving the challenges in these types of structures. Steel-based modular structures have received considerable attention due to their speed, quality control, and reduced waste. Recently, a particular focus has been on the connection of steel modular structures, seismic response, and construction planning [4,8].

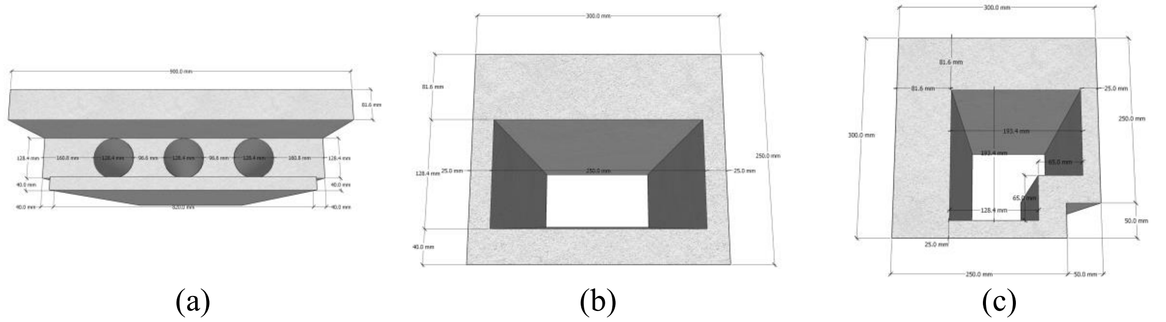
This study examines the parametric development of the MICADO method for use in modular structures. MICADO is a structural method composed of modular systems and prefabricated panels. For this purpose, a case study is selected, and possible challenges and limitations of this method (such as assembling, structural elements, and structural behavior) are examined. A case study includes a modular steel structure analyzed and designed using numerical modeling.

2 MICADO SOLUTIONS

The MICADO method is designed to address the main problems faced by the small building industry, allowing its evolution and application to that of manufacturing. MICADO consists of developing a new advanced building production system, including components produced in autonomous production lines and assembled on-site. This method includes prefabricated thermal insulation panels and structural steel, concrete, or wood-based elements.

2.1 Panels

MICADO elements consist of panels with drilling, rectangular, and L-shaped sections (Figure 1) and with 650mm and 2500 mm high. The panels are clad inside with gypsum plasterboard, and the outside cladding is made of cementitious panels. Panels with drilling sections are used for constructing the facade of the structure. Rectangular and L-shaped panels are used next to the opening and at the corner of the structure, respectively. From center to center, the minimum and maximum distances between the two circular sections are 225 mm and 450 mm, respectively.



(a) (b) (c)

Figure 1. MICADO Elements: (a) Drilling section; (b) Rectangular section; (c) L-shaped section.

2.2 Structure and assembling

Steel profiles were selected for constructing MICADO structures based on the panel's shapes. Figure 2 shows the steps for assembling these types of structures. In the first step, the base plates were executed simultaneously with the construction of the foundation. Then the columns and panels were placed. Next, the main beams placed around the structure were implemented. Then, the columns of the second floor were placed. In the end, the secondary beams were executed to construct the floor and roof.

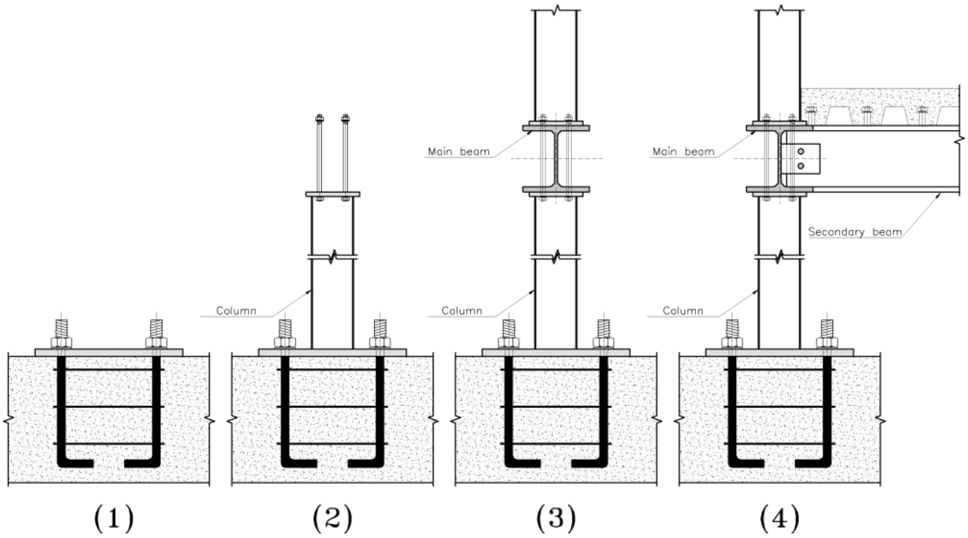


Figure 2. Assembling of steel-based MICADO structures.

3 NUMERICAL MODELING

Linear static analysis was carried out in commercial software, and the elements of the steel-based modular structure were analyzed and designed based on Eurocodes 3 and 8 [9,10]. Figure 3 shows a 3D view of the numerical model. The general case study was rectangular, with 12 m in 7 m and a story high of 3.15 m. The model had four openings with a 3.15 m width at each structure corner. The column distance was determined as 450 mm to consider the critical situation in MICADO structures.

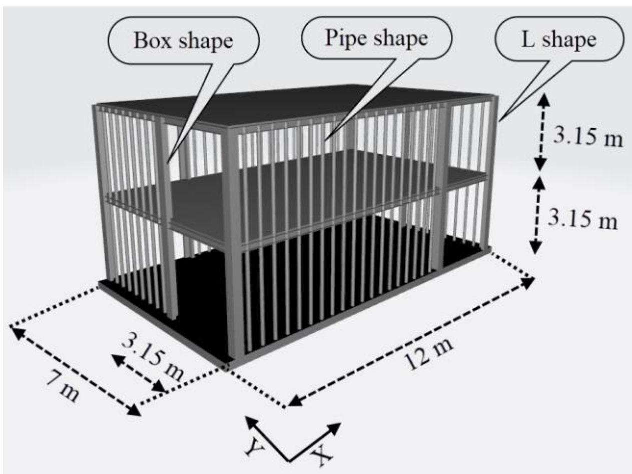


Figure 3. 3D view of the numerical model.

Frame element was used to model beams and columns, including the effects of biaxial bending, axial force, shear force, and deformation of elements. The connection of the secondary beam to the main beam was determined as a hinge joint. The moment-resisting connection was determined for beam-to-column joints. Furthermore, connections between columns and foundations were restrained in all three directions, including translation and rotation.

3.1 Elements

Steel profiles were used for modeling the structure with 240 MPa tensile strength and 200 GPa elastic modulus. Columns profiles were pipe, box, and L-shaped prefabricated profiles, as shown in Figure 4. Furthermore, for both the main and secondary beams H-shaped section was used. The gravity loads were also borne using a steel-deck composite, which includes secondary steel beams and a one-way concrete slab with 110 mm thickness.

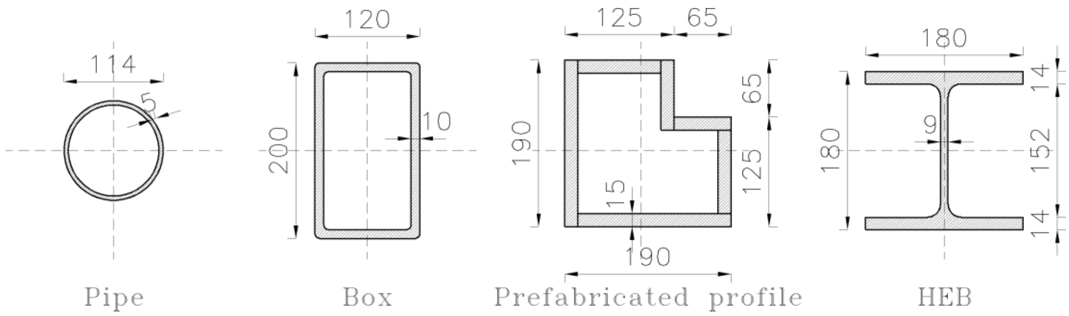


Figure 4. Cross-section of the elements used for the numerical modeling (mm).

3.2 Loading

Gravity load included dead load (DL) equal to 3.5 kN/m^2 and 5 kN/m^2 of floor and roof, respectively. The live load (LL) of the floor and roof was considered to be 2 kN/m^2 and 0.4 kN/m^2, according to [11]. Table 1 reports seismic parameters for a structure in southern Portugal based on Eurocode 8 [9]. In this table, S is the soil factor; T_B, T_C, and T_D are the period of the elastic response spectra; β is the lower bound factor for the horizontal design spectrum; q and γ_1 are the behavior and important factor. Structure mass, including dead and live load, and weight of structural elements that must be included in earthquake analysis were equal to DL +0.8 (0.3 LL), based on [9]. Furthermore, the maximum story drift under seismic load should be less than 0.005 of the height of each story [9].

Spectrum type	Ground Accelera-tion	Ground type	S	T_B	T_C	T_D	β	q	γ_1
1	2.5	C	1.15	0.2	0.6	2	0.2	2	1
2	2.5	C	1.5	0.1	0.25	1.2	0.2	2	1

Table 1. Seismic parameters of MICADO structures for the south of Portugal.

4 RESULTS AND DISCUSSIONS

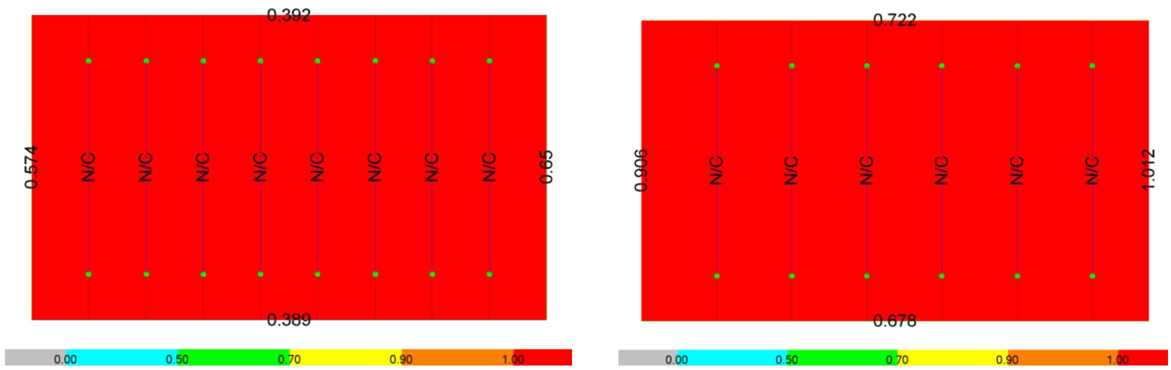
4.1 Strength check

The design of secondary beams is based on bearing gravity loads (dead and live loads) and beam deflection under service loads (DL +0.3 LL). The strength of the structural elements is checked based on the load combinations provided in Eurocode [12]. Eurocode 3 suggested that the maximum deflection of the secondary beam should be limited by L/250 (L is a span length equal to 7000 mm). Therefore, the cross-section required for these elements is HEB 180, as reported in Table 2.

Story	Section	Tributary area [m]	DL [kN/m^2]	LL [kN/m^2]	Deflection [mm]	Flexural capacity
1	HEB 180	1.80	3.5	2.0	29	0.74
2	HEB 180	1.35	5.0	0.4	29	0.55

Table 2. Summary of the secondary beam design.

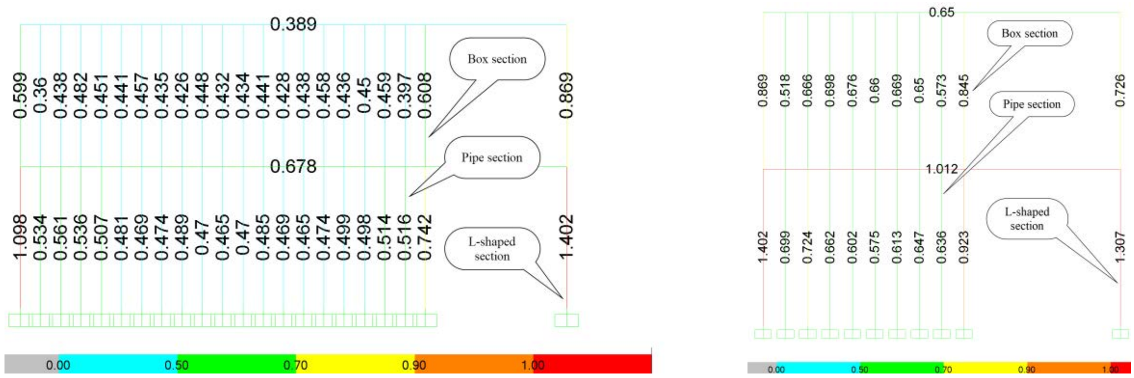
The critical load combination in longitudinal beams includes dead, live, and earthquake loads, while for transverse beams, it combines dead and earthquake loads. Figure 5 shows the bending strength of the main beams, and Figure 6 shows the axial-bending strength of the columns. The moment stress ratio in beams compared to their permissible moment capacity is lower than one, which indicates the section could bear the imposed loads.



(a) (b)

Figure 5. Maximum stress ratio of beams: (a) first story; (b) second story.

The resistance of the regular columns (pipe shape) and columns next to openings (box shape) are also suitable against the incoming loads. However, the first story's corner columns (L-shaped prefabricate) show over stress ratio (of 1.402 and 1.307). Dead, live, and earthquake loads are combinations of critical loads in these columns. When using a plate with a tensile strength of 355 MPa, the maximum stress ratio in these columns is reduced to 0.95.



(a) (b)

Figure 6. Maximum stress ratio of columns: (a) longitudinal direction; (b) transverse direction.

4.2 Stability check

The lateral displacement or drift of the MICADO structure is determined based on Eurocode 8 [9], which is equal to 15.75 mm. Table 3 presents a summary of the story drift of structure (first row), showing that the stories drift in both X (longitudinal) and Y (transverse) directions is more than the maximum value set by the code. While the considered profiles have adequate strength to incoming loads, the system's displacement under an earthquake load can damage nonstructural elements or create a sense of insecurity for residents.

Model	Column distance [mm]	Span [m]	Roof DL [kN/m^2]	D_X- 1st [mm]	D_X- 2nd [mm]	D_Y- 1st [mm]	D_Y- 2nd [mm]
1	450	7	5.0	17.8	17.4	21.8	24.9
2	300	7	5.0	15.1	14.5	19.2	22.3
3	450	7	3.5	15.1	13.8	18.3	19.9
4	450	6	5.0	15.7	15.3	20.2	23.6
5	450	7	5.0	12.3	12.6	15.0	18.0

Table 3. Story drift of the modular structure based on different scenarios.

A parametric study is performed to investigate the effect of different parameters (e.g., column distance, roof DL, span, and sections) on the story drift of the structure, as reported in Table 3. By decreasing the column distance to 300 mm (model 2), the story drift in X and Y directions decreases by 15% and 12%, respectively, compared with model 1. The dead load effect on the drift of the second story is considerable (model 3), so the drift in X and Y directions decreases by 21% and 20%. A decrease in width from 7 m to 6 m significantly affects X direction story drift, but a slight reduction in Y direction story drift (model 4). It means drift in X and Y directions decreases by 12% and 7%, compared with model 1.

If larger sections are used in model 1, the drift of the structure can be controlled to a great extent. However, this increase in cross-section is limited to the dimensions of the MICADO elements (Figure 1). For example, If the pipe and box profiles with 114.3×8 and 245×125×20 sections and the L-shaped profile with a 20 mm plate are used, the drift values of the structure in the X direction for both stories will be less than 15.75 mm. In the opposite direction, it is only valid for the first story. Although in the second story, the drift value is 14% more than the value suggested by the code [9].

5 CONCLUSIONS

In conclusion, the research conducted on the MICADO structure has shown promising results regarding its feasibility and effectiveness as a construction method. The proposed assembly techniques, numerical modeling, and investigations into structural behavior have provided valuable insights into the design and construction of modular steel structures. The research has also explored different scenarios and parameters such as column distance, roof dead load, various spans, and sections to control story drift and ensure the structural integrity of the building.

Furthermore, the research demonstrated the potential of this construction method to revolutionize the building industry. With ongoing advancements in technology and construction techniques, modular steel structures will likely become an increasingly popular choice for a wide range of building types in the future. The insights from this research will be valuable for engineers, architects, and construction professionals looking to adopt this innovative construction method in their projects.

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