Concept design of a steel framed post-disaster shelter utilising containers

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ABSTRACT

Nowadays, numerous earthquakes happen every year with many resulting in large potential aftershocks. Tents and portable dwellings are widely used as emergency shelters. However, tents can only be used for days or weeks, and portable dwellings often provide only for low level of resistance against potential aftershocks. On the other hand, shipping containers are designed for large capacity and long-term transportation, which meets the requirement of emergency shelter in the event of aftershocks. In this paper, a new kind of 2-storey emergency shelter utilizing shipping containers and steel frame is proposed. The prefabricated splicing steel frame is used as the outer support to the container house, taking the most part of the vertical and lateral loads, while containers only bear the gravity loads of themselves. This kind of structure can be easy to set up immediately after an earthquake, and can provide high level of seismic resistance. Numerical model using SAP2000 is presented with different load combinations taking both gravity and seismic load into account, also the choice of section and joint of the prefabricated splicing steel frame are given. From the results, such a combined system shows reliable behaviour under several simulated earthquakes.

Key Words: Shipping container, modular construction, emergency shelter, numerical study, finite element analysis.

1 INTRODUCTION

In recent years, modular buildings have attracted more and more attention. Modular building refers to a building system in which a single room is used as a basic unit, pre-fabricated at the factory, and transported to the construction site to be connected to each other. It has the characteristics of convenient construction, low cost and short construction period. Containers are characterized by standardization, convenient production and transportation.

Most of the existing container buildings are stacked directly on top of one another, resulting in a monotonous structure with minimal access. By introducing an additional framed system, the units can be arranged in different configurations with in-between spaces that can be activated for outdoor living and circulation.

These unit bodies can be repeatedly combined with each other to form a larger building system, or they can be established separately. In order to verify the reliability of this container and steel frame combination system, structural verification and physical construction are required. The unit named Kiosk is small in size and easy to construct. Adjustments have been made to the outer frame, mainly through changing the layout of outer frame and connecting them together to form a structure more suitable for resisting earthquake. The adjusted outer frame is shown in figure 1.

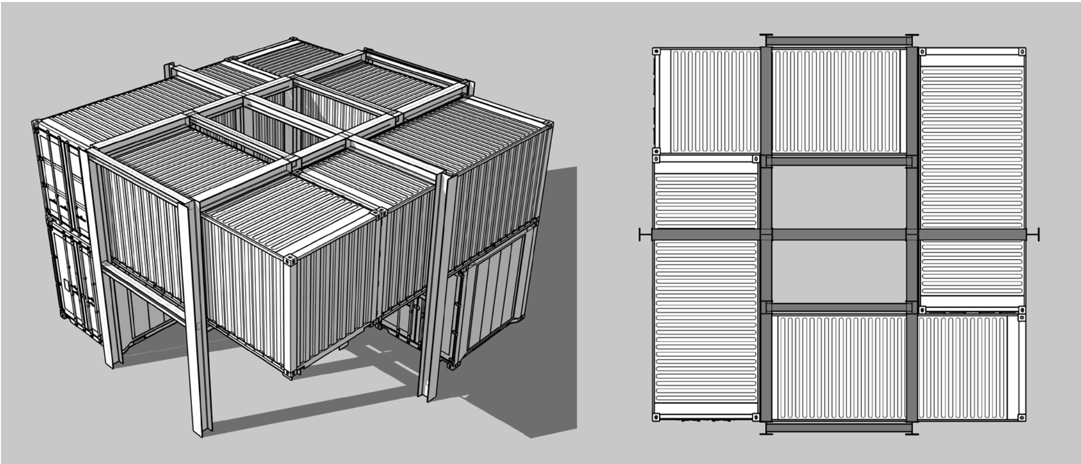


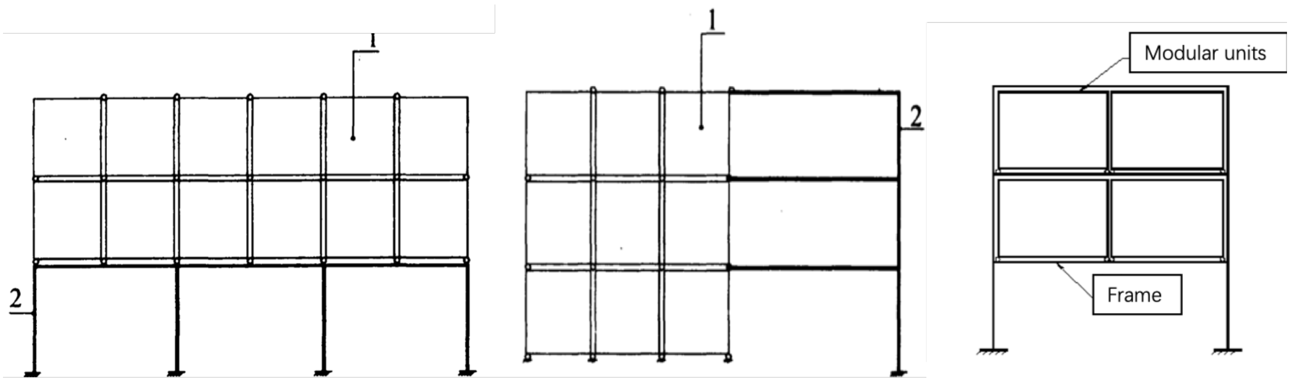
Figure 1. Overview of introduced building

2 BRIEF REVIEW ON THE MODULAR CONSTRUCTION BUILDING SYSTEM

According to the existing modular buildings, Zhang et al (2015), Tianjin University, China, has divided modular buildings into several categories, including: full-module building structure system, modular unit and traditional frame composite system, modular unit and plate structure composite system, giant frame Modular building system, modular unit and shear wall composite structure system. Two commonly used systems namely module structure and frame composite system, and mega frame modular system are briefly introduced.

Module structure and frame composite system include the frame system in the lower part and a modular unit in the upper part, i.e. a bottom frame and modular building composite system, as shown in Figure 2(a). The other type may be a frame system set beside modular units, i.e. support frame box frame system, as shown in Figure 2(b). This kind of system is more suitable for building larger openings.

The system adopted in the design of the container building introduced in this paper is more similar to a mega frame modular building, shown in Figure 3. This system uses frame structure as the outer skeleton to support the installation of non-load bearing module units inside the frame. At this point, the modular unit within the frame is only subjected to its own gravity load. This type of building can not only take advantage of the traditional frame structure, but also meet the bearing capacity requirements, and can also play the role of modular building to reach a high construction speed.



a *b* *c*

Figure 2. Module structure and frame composite system (from CECS 334: Technical Specification for modular freight container building). (a). Bottom frame and modular building composite system,(b). Support frame box frame system (c). Mega frame modular building structure system. 1 and 2 denote modular units and outer frame respectively.

3 DESIGN CONCEPT OF THE EMERGENCY SHELTER

A new structural system combining frame structure and container is introduced in this paper. Since containers are originally used to transport cargos, they have good capacity to carry their own gravity loads and the imposed (live) loads acting inside the container. As a result, only the system of outer steel frames needs to be considered.

One of the significant advantage of this system is that the lateral load are all transferred by the outer frame, allowing to utilize friction joints or dampers between the connection of containers and frames, consequently higher seismic performance can be achieved.

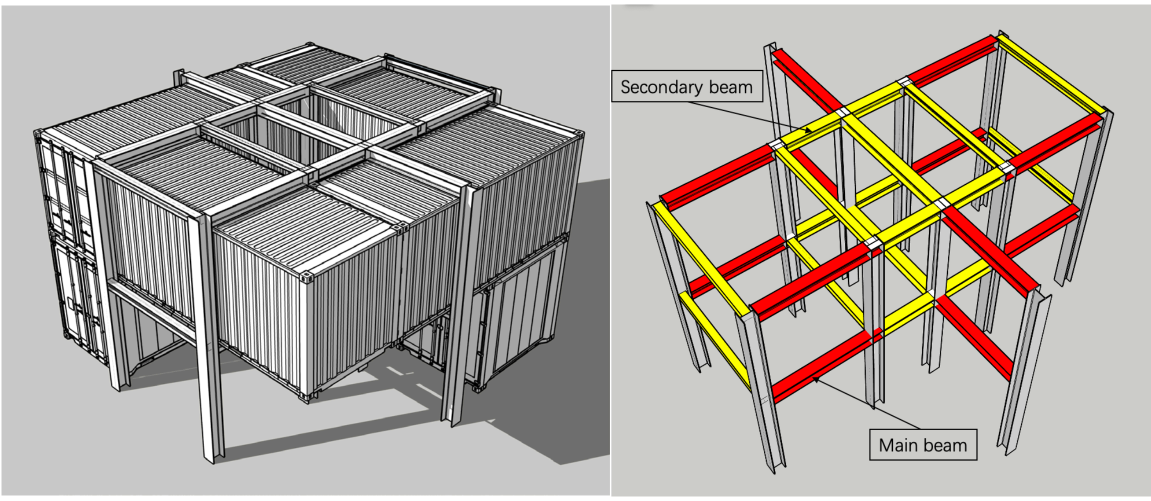
3.1 Design of outer frame

Shipping containers has an ISO regulated dimension, it is shown in the table 1 below. The dimension of containers are restricted by regulations, but their weight may be different. Shipping containers are designed especially for transportation of cargos, which lead to their capacity of resisting their own weight and the weight of cargos inside them.

Layout of the frame is shown in the figure 3 below, with red members referring to the main beams, and yellow members referring to the secondary beams. Main beams are directly connected to the containers, and secondary beams are used for connecting the structure as a whole and increasing the rigidity of the whole structure. For easy onsite construction, bolted connections are recommended. Also, utilizing bolted connections can enable the building to be deconstructed and reconstructed in another place for reuse.

Table 1. Dimension of 20ft and 10ft containers

	Length (m)	Width (m)	Height (m)	Volume (m^3)	Mass (kg)
20ft Container	6.10	2.44	2.62	39	2410
10ft Container	3.05	2.44	2.62	19	1450



(a) *(b)*

Figure 3. Layout (a). Building overview and (b). Frame layout

3.2 Design of vertical system

As mentioned before, container can resist their own permanent (dead) and imposed (live) loads. Hence they can be regarded as a whole system with a distributed load acting on the beam of frames, rather than considering the force distribution inside the container.

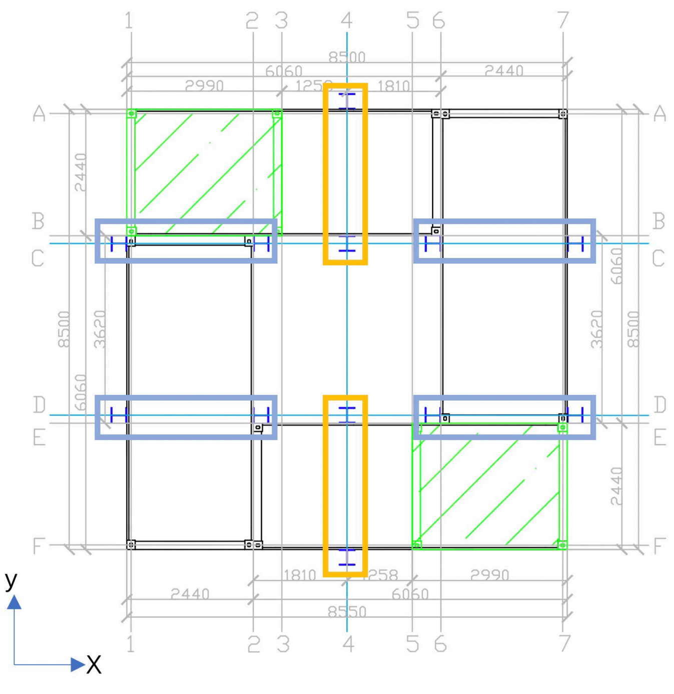


Figure 4. Plan view of structure

The frame system consists of beams and columns. Figure 4 and the architecture drawing in figure 1 shows that the main beams, which connect with containers directly, transfer the vertical dead load and live loads from the containers to the columns, which finally transfer the vertical loads to the ground.

As figure 4 shows, each containers on the second story with its long side on the ***x*** direction is supported by 1 main beam and two columns (shown by yellow rectangle), and there is also a 10ft ISO container on the first story to transfer vertical load. Also part of the vertical load is transferred by beam and column to the ground, and another part is transferred by the 10ft container to the ground.

The container with its long side on the ***y*** direction is supported by two main beams and four columns (shown by blue rectangle). Vertical loads are carried by these beams and columns, and from the columns to the ground.

When considering vertical load, live (imposed) load is taken as 2.0 kN/m^2. Dead (permanent) load is the container and frame weight. Factors of 1.2 and 1.4 are considered for the dead load and live load. These factors are according to China loading standards.

The distributed loads on the main beams are calculated as 12.3 kN/m and 12.1 kN/m for dead and live loads respectively. Through a preliminary design considering axial force and stability, the columns are taken as W section of 200*200*8*12 (mm).

3.3 Design of lateral system

When subjected to lateral loads, such as seismic loads, in order to minimize the structures deformation, the secondary beams are introduced.

In x direction, there are four groups of lateral load resisting frames (shown by blue rectangles in figure 5). These frames are connected with secondary beams. This makes it possible for the four groups of frame to act together to resist lateral loads. In analysis, the x direction system is simplified to a 2D frame, shown in figure 5. The four groups of frame are connected with pinned connection to form a 2D frame.

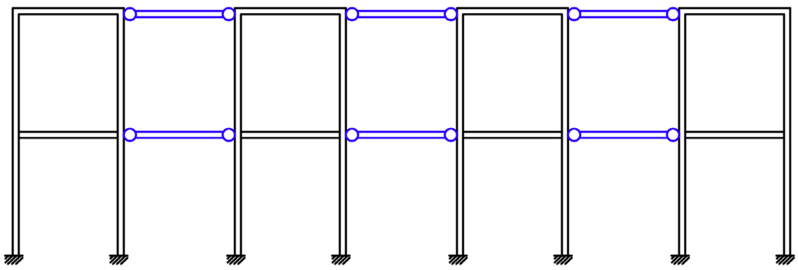


Figure 5. Equivalent 2D frame of x direction

In y direction. The 10ft containers on the first storey are assumed not to participate in carrying the lateral loads. So, there are two groups of frame similar to that of ***x*** direction. As the design shows, the two groups of frame are still connected with secondary beams to let them simultaneously resist lateral loads in the ***y*** direction. Figure 6 shows the lateral load resisting system on the y direction.

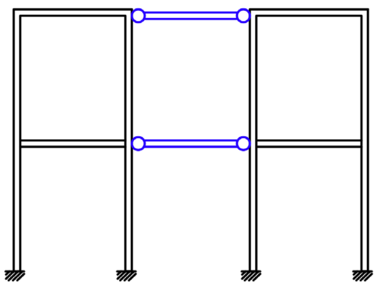


Figure 6. Equivalent 2D frame of y direction

As a concept design, dampers may also be added at the connection of containers and frames. If this can be ensured that the stiffness and strength of the framed system are adequate during an earthquake, the dampers may improve the structural performance by dissipating energy induced by the seismic load. Finally, a system of separating lateral load and vertical load can be achieved. the research is underway by the authors on this subject.

4 NUMERICAL ANALYSIS OF THE OUTER FRAME USING SAP2000

4.1 Modelling of the frame structure

Model is built separately for x and y directions, according to the equivalent 2D frames presented in part 3.

Concentrated plastic hinges are used in modelling, with M3 hinges on beams and P-M-M hinges on the columns. The hinges are taken from ASCE 41-13, table 9-6. Connection between columns and main beams are rigid, and connection between secondary beams and main beams are modelled as pinned. Sections are taken as W sections with the specific dimensions shown in table 2.

Dead load and live load is considered as the same mentioned in section 3.2.

Table 2. Frame dimension with W shape section

	Secondary beams (mm)	**Main beams (mm)**	**Columns (mm)**
Section dimension	125*125*6.5*9	150*150*7*10	200*200 *8*12

4.2 Pushover analysis

In the x direction, taken maximum displacement of the point at the upper corner to be 0.216 m, which is 4% of the total height of the building, the pushover is processed in 100 steps. In y direction, the process is the same, i.e. taking maximum displacement of the point at the upper corner to be 0.216 m, and processing in 100 steps. Base shear-roof displacement relation is shown in Figure 7.

After processing pushover analysis, method of ATC-40 spectrum is used to verify the response under the earthquake. The demand spectrum is scaled to seismic intensity of 0.4g respectively to observe the performance of this structure under a large earthquake. After comparing the demand spectrum and capacity spectrum obtained from pushover analysis results, the performance point in x direction is found at 21th step of push over. Similarly, the performance point was found at 18th step in y direction. Approximated base shear and roof drift ratio is shown in table 3.

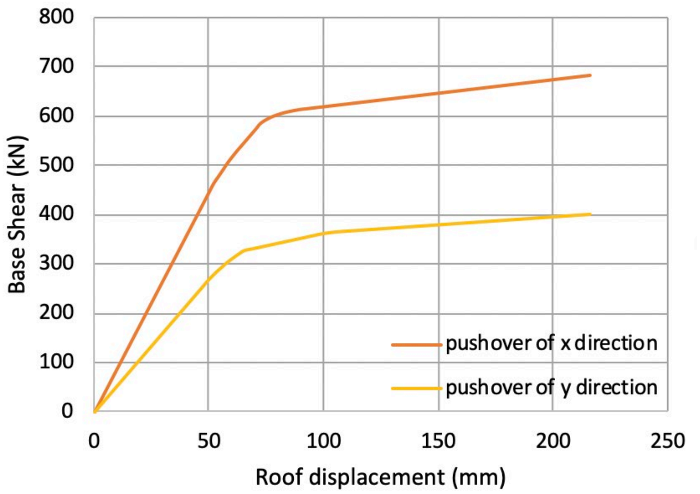


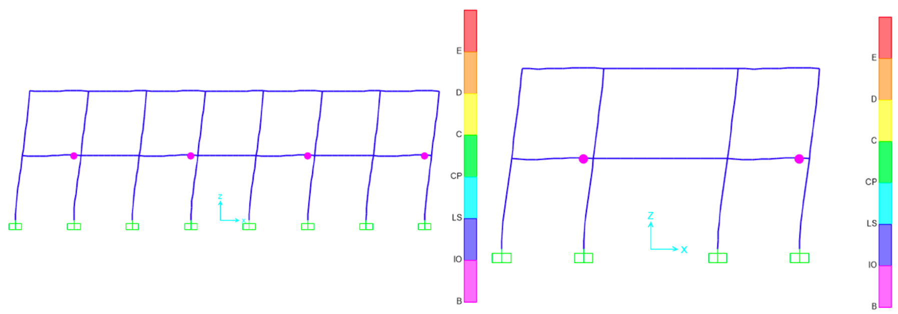
Figure 7. Base shear-roof displacement of the model in x and y directions

Table 3. Base shear and roof drift ratio under considered earthquake

Directions	Base shear (kN)	Roof displacement angle (%)
X	404.3	0.84
Y	208.6	0.92

It may be concluded that in x direction, performance point occurs when the floor displacement is relatively small. The maximum displacement angle allowed is 2% under large earthquake (0.4g) according to Chinese guideline (GB50011-2010). Moreover, from pushover curve, whole structure is still in the elastic stage at performance point. These show that the frame system is capable of resisting seismic loads while maintaining rigidity and small deformation.

Figure 8 shows that plastic hinge first occur at the 2nd floor beam, before expanding to the beam on the 3rd floor and columns. It also shows that under a large earthquake, most of the expected plastic hinges remain in the elastic stage, with only a few of them in the plastic stage which are under IO (immediate occupancy) state. From the results shown above, one can consider that the whole structure still behaves elastically under large earthquakes with intensity of 0.4g.



(a) *(b)*

Figure 8. (a): Hinges at performance point of x direction, base shear of 404.3kN, and Roof displacement angle of 0.84%. (b): Hinges at performance point of y direction, base shear of 208.6kN, and Roof displacement angle of 0.92%

5 CONCLUSION

According to this research, it can be concluded that two floor building utilizing containers and moment resisting frames has a good seismic performance even under large earthquakes. And separating vertical and lateral load resisting systems is shown to be feasible.

Pushover analysis shows small internal actions and displacements of the structure. This is partly attributed to the relatively light weight containers being designed for long distance transportation having the capacity to resist large loads. The seismic mass of the modular building is relatively small compared with that of other kinds of structure, resulting in smaller seismic response.

Low rise buildings have generally higher lateral stiffness and smaller seismic mass compared with high-rise buildings, hence less comprehensive and more straightforward seismic design is required for them. Moreover, low rise buildings are easier to construct than high-rise buildings meaning less time required following an earthquake for affected people to have a reasonably livable shelter.

Consequently it may be concluded that by fully utilizing the property of the containers, a system of separated gravity and lateral load resisting systems may be efficiently achieved.

Further research may be undertaken on the following aspects:

- Connections between containers and frame. As mentioned before, dampers can be added to the connection between containers and frame to achieve better performance in an earthquake.
- Extending this design concept to multi-layer buildings or even high rise buildings. Modular construction has the advantages of quick construction. This design concept may be suitable for modular buildings with more layers
- As an emergency shelter due to achieving fast construction. The construction process can be improved. If the construction time can be reduced from days to only one day, or even hours after an earthquake, it would be much better for quick post-disaster construction.

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