MODIFIED SHIPPING CONTAINERS FOR TRANSITIONAL SHELTER CONSTRUCTION

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ABSTRACT

As the number of displaced people skyrocketed due to natural disaster, conflict and urbanization, the demand of temporary housing solution had increased substantially. As the concept of transitional shelter been proposed to mitigate the issue related to transition stage from temporary shelter to permanent housing, International Organization for Standardization (ISO) standardized shipping container could become a potential candidate due to its modularity and inherent strength. Although ISO did govern that the specification of container had to fulfil requirement for marine and logistic purpose, for residential purpose the container shelter must be modified to include the necessary opening for ventilation requirement. This would greatly affect its structural integrity especially its lateral stiffness that was highly dependent on the condition of corrugated side wall. Hence, this research aims to investigate the ISO container transitional shelter (CTS) from engineering perspective, focusing on its lateral load resistance. Current lateral stiffness design for container wall was revised and modified to include effect of opening by validation of experimental results and design guideline for CTS was developed. Theoretical calculation for lateral stiffness of corrugated panel based on latest publication was modified based on result of lateral load testing using 48 corrugated panels considering effect of panel thickness, opening size, and loading orientation. Two full scale ISO container with different opening configuration were tested under two different loading direction to obtain the lateral stiffness for both axes. Numerical model of ISO container was also developed using finite element software Abaqus and validated with the experimental result. The theoretical calculation developed was then validated with the full scale container test result to amend the formulation for container shelter purpose. From this research, the new correlated formulation proposed could accurately estimate the lateral stiffness of the corrugated panel. Thirteen sets of finite element model were developed, and the correlation factor was proposed to improve the accuracy of current modelling technique. Based on the test stiffness of full scale container, the theoretical stiffness of container shelter was formulated with acceptable prediction when validated with experimental result. Lateral stiffness design procedure for CTS was proposed using the developed theoretical formulation. In nutshell, the research provided update to current stiffness design of corrugated steel shear wall, and the structural design of CTS could become more reliable and flexible in opening layout for engineers by using the new equation proposed.

ABSTRAK

Memandangkan bilangan orang yang berpindah akibat bencana alam, konflik dan proses perbandaran semakin meningkat, permintaan perumahan sementara telah meningkat dengan ketara. Disebabkan konsep rumah perlindungan peralihan dicadangkan untuk mengurangkan isu berkaitan dengan peralihan daripada perumahan sementara kepada perumahan kekal, kontena berpiawai Pertubuhan Standardisasi Antarabangsa (ISO) telah dijadikan calon yang berpotensi disebabkan oleh modulariti dan kekuatannya. Walaupun ISO telah menetapkan spesifikasi kontena yang diperlui untuk memenuhi keperluan tujuan marin dan logistik, untuk tujuan kediaman rumah perlindungan kontena mesti diubah suai untuk memasukkan bukaan yang diwajibkan bagi keperluan pengudaraan. Ini akan menjejaskan integriti struktur terutamanya kekukuhan sisi yang sangat bergantung kepada keadaan dinding sisi beralun. Oleh itu, penyelidikan ini bertujuan untuk menyiasat rumah perlindungan peralihan kontena ISO dari perspektif kejuruteraan, memfokuskan pada rintangan beban sisi. Pengiraan rintangan beban sisi bagi dinding kontena telah disemak semula dan diubah suai untuk mempertimbangkan kesan bukaan dengan pengesahan keputusan eksperimen, diikuti dengan pembangunan garis panduan reka bentuk untuk rumah perlindungan peralihan kontena. Pengiraan teori untuk kekakuan sisi panel beralun berdasarkan penerbitan terkini telah diubah suai berdasarkan keputusan ujian beban sisi menggunakan 48 panel beralun yang mengambil kira kesan ketebalan panel, saiz bukaan dan orientasi pembebanan. Dua kontena ISO skala penuh dengan konfigurasi pembukaan berbeza telah diuji dari dua arah pembebanan yang berbeza untuk mendapatkan kekakuan sisi bagi kedua-dua paksi. Model berangka bagi kontena ISO juga dibangunkan menggunakan perisian unsur terhingga Abaqus dan disahkan dengan keputusan eksperimen. Pengiraan teori yang dibangunkan juga disahkan dengan keputusan ujian kontena skala penuh untuk meminda formulasi bagi penggunaan rumah perlindungan kontena. Daripada penyelidikan ini, rumusan teori baru yang diterima pakai telah dibangunkan dan boleh menganggarkan kekukuhan sisi panel beralun dengan tepat. Tiga belas set model elemen terhingga telah dibangunkan dan faktor korelasi telah dicadangkan untuk meningkatkan ketepatan teknik pemodelan semasa. Berdasarkan ujian kekukuhan kontena skala penuh, kekukuhan teori rumah perlindungan kontena telah dirumuskan dan boleh mencapai ramalan yang boleh diterima apabila disahkan dengan keputusan eksperimen. Prosedur reka bentuk kekakuan sisi untuk rumah perlindungan peralihan kontena telah dicadangkan menggunakan rumusan teori yang dibangunkan. Secara ringkasnya, penyelidikan menyediakan kemas kini kepada reka bentuk kekukuhan dinding ricih keluli beralun, dan reka bentuk struktur rumah perlindungan peralihan kontena boleh menjadi lebih dipercayai dan mudah dalam susun atur pembukaan untuk jurutera dengan menggunakan persamaan baharu yang dicadangkan.

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LIST OF ABBREVIATIONS

ISO	-	International Organization for Standardization
CTS	-	Container transitional shelter
UN	-	United Nation
SWOT	-	Strength, weakness, opportunity, threat
TELOS	-	Technical, economic legal, operational, and scheduling
ASTM	-	American Society for Testing and Materials
BSI	-	British Standard Institution
ECCS	-	European Convention for Constructional Steelwork
UBBL	-	Uniform Building By-Laws
SPSW	-	Steel-Plate Shear Walls
FEM	-	Finite Element Model
PV	-	Photovoltaics
FRP	-	Fire resistance period
m	-	metre
ft	-	foot, equal to 0.3048 m
kg	-	kilogram
MPa	-	Megapascal (1 N/mm^2)
N	-	Newton (1 $kg \cdot m/s^{-2}$)
C	-	Carbon
Si	-	Silicon
Mn	-	Manganese
P	-	Phosphorus
S	-	Sulphur
Cu	-	Copper
SG	-	Strain gauge

LIST OF SYMBOLS

f_y	-	yield strength
f_u	-	ultimate strength/ Tensile strength
F	-	applied force
a	-	width of panel in direction perpendicular to corrugation
b	-	depth of panel in direction parallel to corrugation
b_T, b_S, b_B	-	width of top plate, side plate and bottom plate respectively
t	-	net panel thickness
h	-	height of sheeting profile
d	-	pitch of corrugation
E	-	elastic modulus of steel
K	-	sheeting constant in ECCS
v	-	Poisson's ratio
A_d	-	total opening area of panel
μe	-	micro strain
δ	-	displacement of panel given by LVDT
Δ	-	shear deflection of panel
Δ_i	-	shear deflection of single corrugation
c	-	shear flexibility (mm/ kN)
V	-	shear force
u_T, u_S, u_B	-	bending deformation of top plate, side plate and bottom plate respectively
γ_T, γ_S, γ_B	-	shear deformation of top plate, side plate and bottom plate respectively
v_T	-	axial deformation of side plate
θ_B, θ_C	-	corner rotation of corrugation section at corner B and C
Φ_B, Φ_C	-	chord rotation of corrugation section at corner B and C
M_B, M_C, M_D, M_E	-	end moment of corrugation section at corner B, C, D and E
M_y	-	Bending moment of corrugation plate
U_{Top}	-	Top plate energy

U_{Bottom}	-	Bottom plate energy
U_F	-	Energy due to out-of-plane bending of corrugation section
s	-	total perimeter of corrugation ($2b_T+4b_S+2b_B$)
D	-	ending stiffness (flexural rigidity) of the plate
U_B	-	Energy due to in-plane bending of corrugation plate
U_S	-	Energy due to shear strain of corrugation plate
A_S	-	cross sectional area of plate
G	-	Shear modulus
τ	-	Shear stress
U_T	-	Energy due to axial deformation of side plate
N_S	-	Axial load along the side plate
U	-	Total strain energy due to unit shear deformation per corrugation
E_T	-	Total strain energy due to shear deformation per corrugation
k	-	Transverse shear stiffness of corrugated panel
k'	-	Longitudinal shear stiffness of corrugated panel
e	-	horizontal projection of the corrugation section

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CHAPTER 1

INTRODUCTION

1.1 Research Background

The increasing report of natural disasters had been observed worldwide over the past decades. According to the statistics by The United Nations Office for Disaster Risk Reduction, total of 98.6 million people had been affected by the natural disaster with over 66.5 billion US dollar economy damage in year 2015 alone (Centre for Research on the Epidemiology of Disasters (CRED), 2016). Besides, the conflicts within and among the countries such as civil war, persecution or revolution encouraged the migration of residents as refugees. The United Nation Refugee Agency had reported that till 2016 there were 22.5 million refugees and 20 people were forcibly moved from their home every minute (UN Refugee Agency (UNHCR), 2017). Combined with the victims from the natural disasters, these whooping numbers of people were waiting for all sort of emergency aids including food, medicine and shelter as their protection and livelihood.

In general, conventional post-disaster shelters can be categorized into emergency shelter, temporary shelter, temporary housing, and permanent housing (Quarantelli, 1995). When disaster occurs, the affected people will attempt to find emergency shelter to protect them, at most overnight, before the arrival of the rescue. Temporary shelter is the place where the displaced people are settled and stayed before they can move into new housing. In some cases, especially when large crowd of population are involved or the construction of permanent housing requires long period of time, temporary housing will be provided too as alternative measures. Temporary house is more structurally robust and comfort to live compared to emergency and temporary shelter, however it is still not designed for long service life.

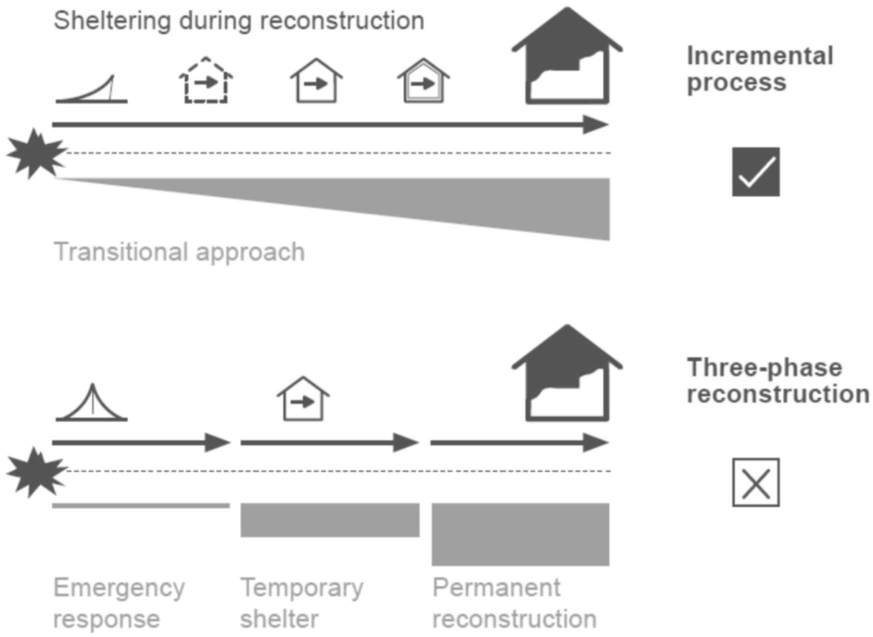

Figure 1.1: Concept of transitional shelter (Shelter Centre, 2012)

Currently transitional shelter had been introduced into disaster relief programme as the substitute of the traditional approach. Transitional shelter is defined as an incremental approach to provide shelter which can be upgraded, reused, relocated, resold and recycled (Shelter Centre, 2012). This is illustrated in Figure 1.1. It had been implemented since year 2004 at several disaster regions such as Sri Lanka, Jogjakarta, Aceh, Peru and Haiti (UN-HABITAT, 2009). Compared to conventional approach which is carried out phase-by-phase, transitional shelter is rather a continuous development of improving existing shelter which may become the permanent housing by itself.

The International Organisation of Migration (IOM), in its publication, had carried out strength, weakness, opportunities and threat (SWOT) analysis of transitional shelter which were summarised in Figure 1.2 (Shelter Centre, 2012). With careful decision-making and detailed planning based on local scenario and available resources, the transitional shelter can become potentially the best solution for housing crisis after the migration of displaced people from conflict or disasters. The common types of material used in transitional shelter are bamboo, timber and steel frame (International Federation of Red Cross and Red Crescent Societies, 2011). Recently, another potential candidate had gained attention from researcher as transitional shelter that is used ISO shipping containers.

Figure 1.2: SWOT analysis of transitional shelter (Shelter Centre, 2012)

1.2 Problem Statement

Current emergency shelters provided for disaster refugees are complained about too late, too expensive and contradict to local culture and living needs (Johnson, 2007). An emergency shelters, i.e., camp shelter that meant for temporary use of 6 months are often being prolonged into years of utilization, while waiting for government to provide permanent dwells. These temporary shelters are also not designed to withstand strong natural impacts like wind gusts, floods and land movement which exposed the refugees to the hazards of second wave of natural disaster impacts. The tarpaulin and canvas camp material do not provide sufficient security for the refugees to protect their lives and belongings over social crimes. Conversely, provisions of timber and brick temporary shelters to the refugees would solve some of the mentioned problems but they are not a sustainable solution. When the refugees move out form the temporary disaster camp into a permanent shelter, the abandoned timber and brick shelters will become huge amount of waste that need another budgets and efforts for disposal. Urge for an improved shelter design is needed, which is available immediately, rapid and ease construction, open-ended design that adaptable to local social and cultural needs, pre-designed for long-term usage, cost effective and environmentally friendly. With these demands in mind, steel modular building such as modified ISO shipping container could serve as good solution. The term “modified” used in this context refers to modification which will deteriorate the structural performance of shipping container, such as aperture for ventilation and installation of heavy machinery such as air conditioner. The idea of using modified shipping container as container transitional shelter (CTS) was visualized in Figure 1.3. With its capability to be arranged in different orientation and stacked on each other, the modularity of container shelter could be used as buildings for multi-purpose (Hong, 2017). The uses of container as housing materials had been popularised due to its construction speed, waste reduction and modular construction (Nduka et al., 2018). It can also be used in different kind of terrain or climate including coastal region (Haque et al., 2022). ISO shipping containers manufactured to ISO 668 specification can withstand extreme natural impacts and weather conditions. Reusing ISO shipping containers as shelters for their second life purpose can save up to 95% energy compared to recycling them into raw steel materials that made it a sustainable construction solution (Vijayalaxmi, 2010).

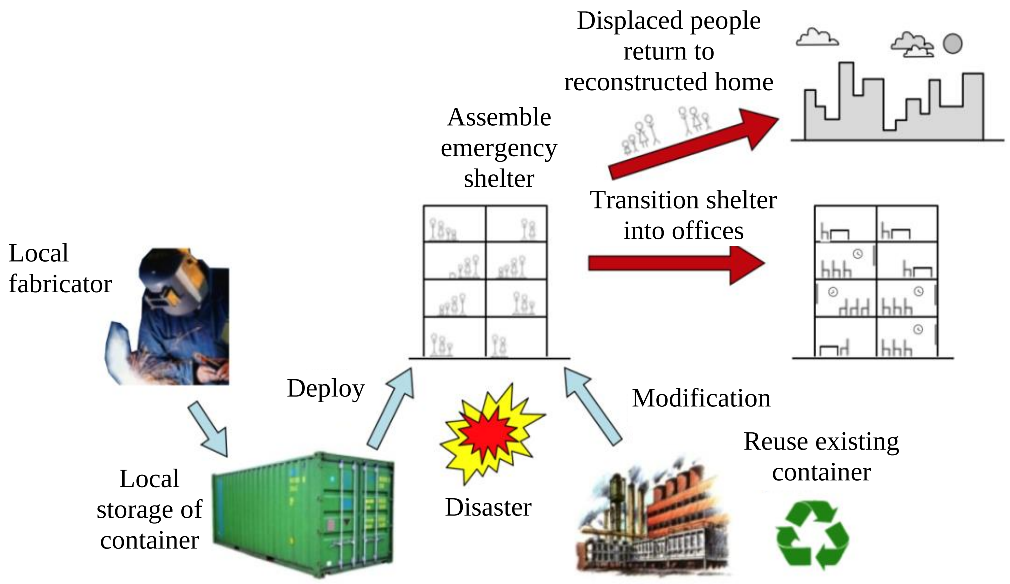

Figure 1.3 Idea of modified ISO container transitional shelter for disasters (Prinz & Nussbaumer, 2014)

Although some studies on the container had been done, they only investigated container strength as whole without prioritizing the load condition of residential purpose (Børvik et al., 2008a; Zha & Zuo, 2016a). The research done on container shelter also did not assess all structural performance, especially its resistance under lateral load (Bernardo et al., 2013; Zafra et al., 2021). Hence there is an urge for the stiffness prediction of the container shelter as the deflection control was especially crucial for container module which could be stacked up to form mid-rise building. The structural performance of container shelter should also be investigated using more advanced engineering approach such as finite element software. Moreover, although ISO shipping containers carry the structural integrity as guaranteed by ISO standards, used and modified containers would cause the warranty voided. Container architects and builders diligently recommend the sustainability of container houses, but to date, no professional personnel or organization has provided a code of practice to the design and build of CTS. This causes the CTS idea is hardly accepted by the public, e.g., residents, insurance companies and bank etc. A comprehensive scientific and engineering study must be conducted to provide a design procedure for the CTS.

1.3 Objectives of Research

The aim of the research is to investigate the potential of ISO shipping container as transitional shelter from engineering perspective, especially its structural integrity on the lateral load.

The objectives of the research are:

1) To modify and formulate new engineering formulation for the lateral stiffness of modified ISO shipping containers.

2) To determine the correlation factor through numerical analysis and theoretical formulation for stiffness of modified ISO shipping container shelter.

3) To develop and propose the design guideline for container transitional shelters.

1.4 Scope of Research

A scaled experiment had been conducted using 48 commercially available steel panel to verify the theoretical calculation on lateral stiffness of corrugated profile given by current code of practice. Different set of panels with various net thickness, opening size and loading orientation were tested and the lateral stiffness, maximum load, failure mode and strain data were obtained. Parametric study was carried out to compare the test results to previous analytical models. The existing formulation given by code of practice was modified to include effect of opening for more accurate representation.

Two full scale 20ft ISO containers with different wall opening were also tested under lateral loading from two different principal axis. The load-deflection relationship, deformed shape and strain data were collected. Besides, numerical model of a 20ft ISO container was modelled using finite element software Abaqus. The load-deflection analysis was carried out on modified numerical model with same opening configuration as full scale experimental specimen. The results of numerical model were compared with previous research outcome and the full scale test result to validate the accuracy of numerical model. The results of full scale container would also validate the theoretical formulation developed in previous scaled down test.

The stiffness design for CTS was developed by proposing calculation workflow with inclusion of modified stiffness formulation and consideration of wall opening. A work example was demonstrated for lateral stiffness design of single storey container shelter.

1.5 Significance of Research

The integration of ISO shipping container as rapid steel modular construction system would provide a safer and withstandable structure, open-ended design that adaptable to local social and cultural needs, rapid and ease construction, lightness, economic and sustainable shelters compared with conventional shelters for emergency, temporary or long tern usage. The study also contributes to the rapid construction for post-disaster reconstruction and re-urbanization. As parts of this study was focused on the stressed-skin design, the revision of the existing design guidelines can be used in other types of steel modular construction, helping engineers to predict the structural performance of their design under lateral load such as wind. This study is also necessary to understand the structural integrity of modular steel building using ISO shipping container. The study provides further justification, modification and proposed operative procedures to implement the steel modular building as emergency shelters. The demonstrated workflow with revised formulation and design approach achieves more precise representation on the structural stiffness of container shelter. The proposed design workflow of container shelter was supported with results from both theoretical and numerical data, which validated with experimental results and thus be more accurate than previous research. Development of numerical analysis using finite element approach enlightens the structural engineers to simplify the structural analysis of container shelter using computation power of engineering software.

1.6 Thesis outline

This thesis was comprised of six (6) chapters. Chapter 1 described the introduction of thesis including research background, problem statement, research objectives, scope of research and research significance. Chapter 2 consisted of literature review on the ISO shipping container, container architecture, housing design consideration and previous research on container structure. Chapter 3 consisted of research methodology for development of theoretical calculation, experimental setup of both scaled down testing and full scale ISO container test, and development of numerical model and finite element analysis. Chapter 4 depicted on lateral stiffness of corrugated wall by scaled down experiment. Chapter 5 depicted the validation of test result of full scale ISO container test with both theoretical and numerical model, together with the stiffness design guideline of CTS. Chapter 6 was the conclusion for the research and future work recommendation.

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