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PREVENTION OF CRACKS AT CONNECTIONS BETWEEN LIGHT GAUGE STEEL COLUMN AND LIGHT WEIGHT BLOCK WALL SYSTEM

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ABSTRACT:

Real estate industry in Thailand has increased using the cold-rolled Light gauge steel due to its excellent properties such as lightweight, rusting and corrosion protection, high yield strength, quick and easy installation, which results in economic construction and less environmental impact. Currently, building structural system consisting of steel and reinforced concrete columns have been substituted by the system of light gauge steel columns connected with the lightweight block wall panels. However, several surface cracks have been found at joints between the light weight block walls and the light gauge steel columns. These cracks are thought to be due to higher tensile stress than the strength of material at joints. These stresses can be caused by wind force, expansion and shrinkage of material due to changes of temperature and humidity, vibration from construction, trucks or vehicles, and etc. This research studies on comparison of stresses at joints between various cases of FE modeling structural analysis and experiments. The experiments were to measure bending stress capacity at joints between the lightweight block wall panels connected with the light gauge steel column. The bending stress capacity is used as an allowable tensile stress at joint surface. The compared results from the structural analysis were performed under load cases of wind force, temperature change, and traffic vibration which were measured as velocity at wall surface during construction and acceleration at building base. The results show that the connection between light gauge steel columns and light weight block wall panels using dowel bars or metal straps increases the strength at joint as well as applying the square wire mesh at joint for block plastering work. However, for condition with all load combinations including dead load, live load, wind load, temperature change and traffic vibration, all cases of present connection between light gauge steel columns and light weight block wall panels have not enough strength to prevent crack. The recently used connection can increase joint strength to prevent crack only for usual condition of combination between dead load, live load and traffic vibration. If wind force or temperature change is presented, more dowel bars or metal straps are necessary, even if additional structural components may be needed to be considered.

KEYWORDS: light gauge steel, light weight block wall, joint connection, crack

1. Introduction & Background

Steel has been used in construction for long time as its properties are appropriate in many aspects; such as, steel has high load capacity; its ductility is efficient for earthquake resistance and rehabilitation; using steel can reduce dust and sound in construction and can be easily used; the production has good quality control, etc. However, steel has some disadvantages; such as, rust prevention, experience necessity, and price fluctuation in construction market. At the same time, many new construction materials have been introduced in order to reduce labor, construction cost, environmental impact such as using biomass materials in concrete block [1], or improve construction efficiency and construction time. One material that has been introduced and widely used around the world at present; such as in Australia, Canada and USA., Sweden and many countries in Europe, also in Thailand, is the light gauge steel together with other materials such as gypsum board, insulated panel, etc. [2]-[6]. The light gauge steel is high strength cold formed steel with galvanized coated, has advantages in less weight, high yield strength, rust protection, fast installation and less environmental impact.

There are many studies about advantages of using cold-formed steel and light gauge steel system such as the followings [7]-[9]:

The experimental study was undertaken to investigate the mechanical properties of high strength steels and cold-formed steels. The yield strength and elastic modulus were predicted with improved equations and the new predictive equations were proposed [7].

The earthquake performance of light gauge steel framed house structures has been both experimentally and analytically studied and evaluated [8], which the results show that the cold-formed steel framing houses, perhaps, the best structural solution for such a type of building located in seismic areas. Moreover, the finishing materials on the light gauge steel structures have been found to contribute a significant damping effect on earthquake resistance in the case of these constructions.

S. Gunalan et al. [9] have tested the light gauge steel framing walls for the thermal and structural performance, fire resistance rating of walls under different load ratios. The walls had several configurations including single or double layers of plaster boards with and without cavity insulation and external insulation composite wall panels. Test results show that the cold-formed steel wall systems with external insulation provided higher fire resistance rating than the conventional cavity insulation wall systems. The research has presented valuable structural and thermal performance data for the light gauge steel wall system.

In contrast to the expanding of steel market over decades in Thailand; hot rolled steel, aluminum-zinc coated metal sheet, etc., there are few amounts of the light gauge steel manufacture for light weight steel framing products. This causes obstacle to the development of the light gauge steel market as there are less steel sections that engineers can select which results in limitation in use of the light gauge steel [10]. Construction problems also occurred during installation on site which may come from mistake in drawings, coordination and lack of knowledge [11]. The same situation of steel and light gauge steel markets in China is similar to Thailand [12]. The system is not universally utilized. Rural and small towns have not yet applied. The standard is not in conformity with the norms of domestic, which may result in additional construction cost and not the competitive solution. Anyhow, it can be predicted that light steel structure residential will be a wide range of development in near future follow the growth of technologies.

The appropriate design method and procedure of cold-formed steel in Thailand [13] has been studied following the prescriptive method issued by the National Association of Home Builders (NAHB, [14]) of the USA which has enhanced the cold-formed steel use for residential construction and made the engineering and construction more successful in the USA. However, the design method issued by NAHB is not suitable for house construction in Thailand due to the difference of loading criteria. The study had developed the tables for selection of member sections to facilitate the design of cold-formed steel framed house construction based primarily on Thai building law. Members prescribed in the tables are the main structural components for inline framing concept. However, it needs engineering judgment and restricts engineers from doing more refined calculation to achieve more economical size of steel. In cost comparison, it shows that cold-formed steel house is 9.8% less expensive than the conventional reinforced concrete house due to shorter construction time.

Formerly, the light gauge steel has been widely used in Real estate industry for roof structure, but now it has been substituted to the structural steel or reinforced concrete column as shown in Figure 1. One main problem of using the light gauge steel framing walls system (light gauge steel columns connected with light weight block walls) is that several cracks have been observed on block wall surface especially at location of joint between Light gauge steel columns and the light weight blocks [15]. There may be several causes of these cracks such as bad construction techniques, low quality of materials, less thickness of plastering compared to conventional brick system, not enough lintel lining works for block walls, etc. One main reason may probably be excess of strain and stress over material strength at wall surface due to external force such as wind load, temperature change, vibration during construction, etc.

Figure 1 Use of light gauge steel and block wall for real estate industry in Thailand

In this paper, the efficiency of light gauge steel with light weight block wall system using different types of joint connection to resist crack on wall surface is experimentally performed and compared with the FE analysis of structure under several load cases. As a result, method to reduce cracks on wall surface using the appropriate joint connection between the light gauge steel and the light weight block wall is proposed.

2. Experimental study

There are 4 types of experiment performed in this study. First experiment was conducted to test for bending capacity of the light gauge steel columns and light weight block wall system with different joint connections in order to obtain the stress capacity of the wall. The second one was the experiment to consider vibration at the construction site by measuring the peak particle velocity. The third experiment was to measure the acceleration at the construction in or der to obtain input data for FE analysis of the structure under several load cases. The last type of experiment was to measure the temperature at the construction site as the temperature change may be one reason of cracks found on the light gauge steel column with the light weight block wall system.

2.1 Test for wall bending capacity

Samples of wall panel with the total size of 610 mm width x 400 mm height x 150 mm thickness were bricked using the 125 mm thickness light weight block. The wall was separated into 2 parts using the light gauge steel column as a connection at center. The section of C-10019 light gauge steel [16], C section with 100 mm depth and 1.9 mm thickness, was used. Four different types of connection by combination of dowel bars, square wire mesh or metal strap were considered at the connection of the light gauge steel in this study as shown in Figure 2, and one type without connection as a reference sample. Each type of connection is referred as follows;

Type 1: Connection with dowel bar and wire mesh

Type 2: Connection with dowel bar, but without wire mesh

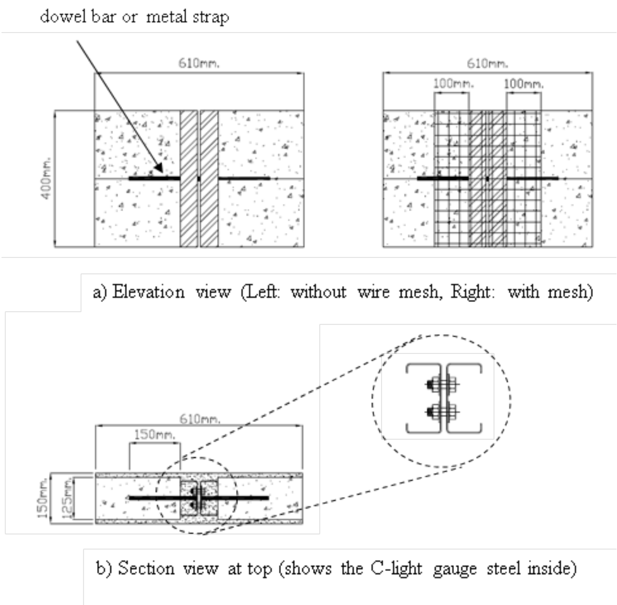

Figure 2 Combination of connections at joint for samples in different types

Figure 3 Material used in experiment (block wall, C-light gauge steel, wire mesh roll, dowel bar and metal strap)

Figure 4 Production of the experiment samples

Type 3: Connection with metal strap and wire mesh

Type 4: Connection with metal strap, but without wire mesh

Type 5: No connection (Reference case)

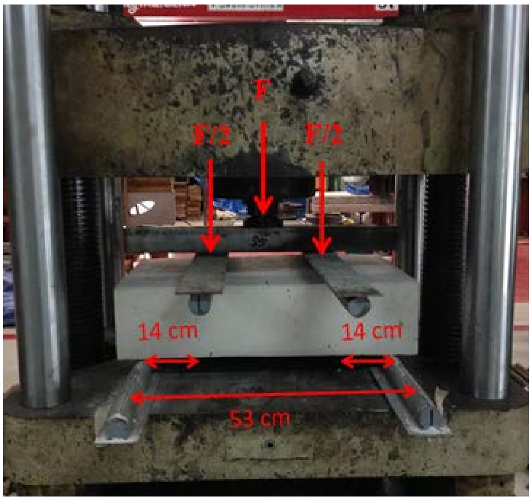

Figure 5 Setup for bending stress test

The steel rod of 9 mm diameter round bar, grade SR24 (yield strength of 2,400 ksc), was used as a dowel bar connecting between the light gauge steel column and the light weight block, or use the 25x300 mm metal strap instead of the dowel bar. For sample type with mesh, the square wire mesh generally used in the architectural brick wall was applied and covered on the connection joint at wall surface for plastering work. The material used in the experiment was shown in Figure 3 and Figure 4 shows production of the experiment samples. Three samples were produced for each type of connection, so there were totally 15 samples. The samples were weighed and the average weight of the wall panel was found to be about 46 kg.

2.1.1 Test for wall bending capacity

The wall panel was laid horizontally and tested with 4 points test experiment for wall bending using the Universal Testing Machine as shown in Figure 5. The span length of bending test between support to support was set at 53 cm, and the position of the applied load was set at 14 cm from each support. The tests were performed 28 days after curing of the produced wall panels. The 4 points test method helps to obtain the result in form of the applied load and moment acting on the member without the effect of shear force. Therefore, the bending stress, σ, at wall surface can be obtained from the relationship of

$$\sigma = \frac{Mc}{I} \tag{1}$$

Table 1 Bending test results (The maximum applied load and the bending stress)

Experiment type	Type of connection			Maximum applied load, F_{max}, (kg)			Average force (kg)	Bending stress (ksc)
	Dowel bar	Metal strap	Wire mesh	Sample No.1	Sample No.2	Sample No.3		
Type 1	o	-	o	1,682.00	1,149.50	1,284.20	1,371.90	**6.16**
Type 2	o	-	-	380.87*	1,276.50	1,072.00	1,174.25	**5.40**
Type 3	-	o	o	1,242.60	1,820.20	1,214.40	1,425.73	**6.43**
Type 4	-	o	-	1,349.10	755.22*	1,191.20	1,270.15	**5.70**
Type 5	-	-	-	1,352.38	859.25	1,008.98	1,073.54	**5.16**

* Sample was cracked during transportation (result was not include in calculation)

where M can be calculated from the applied load, c is the vertical distance from neutral axis which, in this case, is half of the wall thickness and I is the moment of inertia of the wall. At the initial testing condition, as the samples were set horizontally, self-weight of the wall panel also caused the initial bending stress in the wall which can be calculated in the same way. The initial bending stress shall be added to the bending stress result due to external applied load in order to obtain the total bending stress capacity of the wall panel. Thus, the stress at bottom surface of the wall undergoes the normal tensile stress.

In the experiment, the load was applied on the wall till the wall failed. Cracks were found beginning from bottom surface of the sample (the side that subjected to tensile force due to bending) to top surface as shown in Figure 6, or in some cases, the cracks went to position of the supports.

The maximum applied load obtained for each sample and the calculated bending stress are presented in Table 1. It can be seen from the results that the light gauge steel column with the light weight block wall system using the metal strap connection covered with wire mesh on plastering gave the highest bending stress capacity (6.43 ksc) compared to other types of connection, which is about increasing of 25% from the bending stress capacity of the pure block wall system without connection (5.16 ksc). The increasing bending capacity for each type of connection from the reference case (experiment type of block wall without connection) can be determined by the ratio of the bending stress capacity of each type compared to the

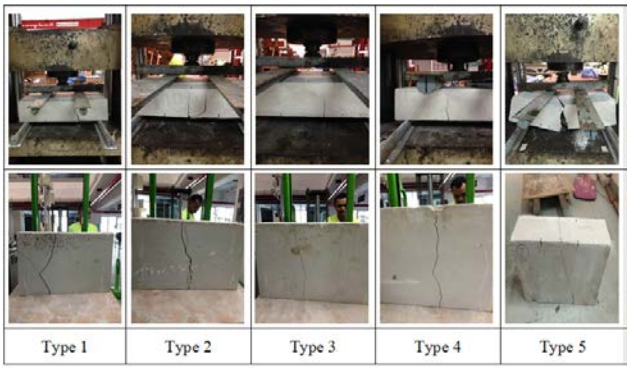

Figure 6 Cracks found in test

base case, which are 19%, 5%, 25% and 10% for connection type 1, 2, 3 and 4, respectively.

2.2 Vibration measurement at the construction site

Since there are many trucks and trailers travelling at the construction site, they induce vibration and may affect wall of the building and cause cracks. Firstly, vibration at the construction site was measured by considering the value of Peak Particle Velocity, PPV, to verify that the vibration level at site was severe or not. According to the Announcement of the National Environment Committee No.37 (in 2010) [17], the standard provides that, in order to prevent vibration effect on the building, the value of PPV shall not to exceed 15 mm/s at top floor for the residential building.

The instrument was installed on top floor of the sample house at construction site as shown in Figure 7. The measurement was taken continuously for whole 2 days that many activities were presented in the construction site. However, the instrument can

Figure 7 Instrument for PPV measurement at site

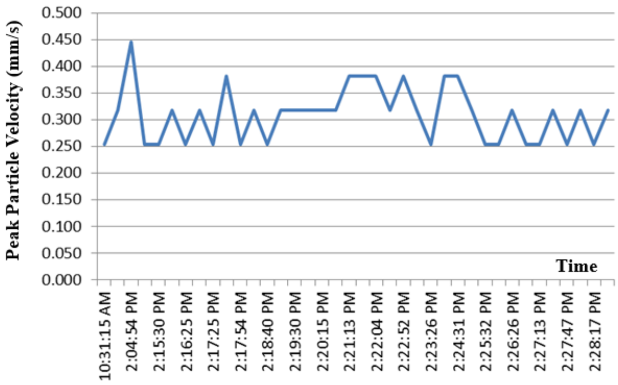

Figure 8 The measured PPV at the construction site

Figure 9 Measurement of the acceleration at site

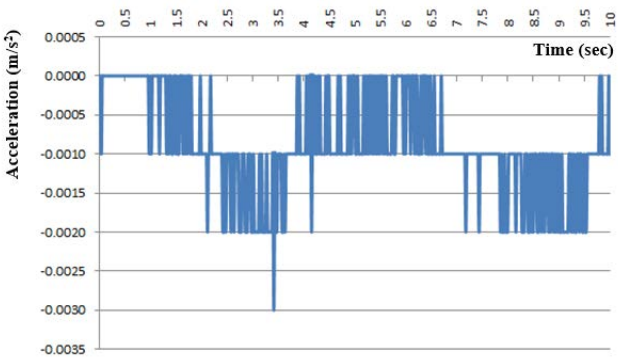

Figure 10 The measured acceleration at the construction site

measure only horizontal vibration. The measured results are shown in Figure 8 for the duration that highest level of vibration was observed. It can be seen that the maximum PPV is only about 0.45 mm/s which is much less than the limit of the standard. Therefore, it can be implied that vibration at construction site in this case had no effect on the building or to the wall. In other words, vibration is not the main cause of cracks on wall surface.

2.3 Acceleration measurement at the construction site

In order to include effect of vibration in the FE analysis, the effect of vibration in term of the acceleration was measured at the construction site. By obtaining the acceleration data, the force acting on the building can be computed. Due to limitation of the equipment, the measurement was taken at site in day-time for 2 consecutive days only when there was piling work, since it was expected that there would be most vibration. The acceleration sensors were installed at wall surface on the first floor near ground as much as possible in order to detect the vibration from piling rig as shown in Figure 9. The data was measured with 50 Hz frequency for duration of about 6.67 minutes. (the total data is 20,000 for one measurement).

Figure 10 presents the maximum acceleration found at the construction site, about 0.003 m/s2 at time = 3.42 second, which is very small compared to the peak ground acceleration considered in Earthquake resistance design for building in Bangkok. The obtained data shall be used as input acceleration in the structural model in the FE analysis part of this study.

2.4 Measurement of Temperature at the construction site

Temperature at the construction site was recorded in the middle of April for 24 hours as this period is expected to have the highest temperature in Thailand. The measured temperature is shown in Table 2. It can be seen that the hottest time was in the afternoon around 13:20PM with the temperature of 33.5°C, while the coldest time was at early morning around 5:35AM with the temperature of 27°C. Thus, it

Table 2 Temperature at the construction site

Time	Temperature (°C)
5.35 AM	27
6.50 AM	28
11.00 AM	31
13.20 PM	33.5
14.50 PM	31.5
21.00 PM	27

can be implied that the temperature change in one day was about 6.5°C.

Data of the temperature change above shall be applied to the FE analysis of the structural model in this study.

3. FE analysis of the structural model

The finite element analysis of the structural model of housing is presented in this part. The analysis is to compare the results of stresses occur on wall due to various excitations with the stress capacity of wall obtained from experiments in order to verify efficiency of joint connection between the light gauge steel column and the light weight block wall.

3.1 Structural model in analysis

The prototype structure of 3 stories residential commercial house as shown in Figure 11 was selected for performing FE analysis. Two blocks of the commercial house were considered and modeled using SAP2000 software. The building in the model is 10.0 m. wide, 9.60 m long and 14.6 m high. Height of each floor is 4.80, 3.30, 2.27 and 3.34 m for 1st, mezzanine, 2nd and 3rd floor, respectively. Frame element was used for modeling beams and columns of the house and shell element was used for modeling floors and walls. The load cases considered in the analysis consist of Dead load (DL), Live load (LL), Wind load (WL), Temperature change (TC) and Vibration load (VB). Applied load in the analysis followed the building structural design criteria of Thailand; the Building control Act [18], which Live load for residential commercial house is 200 kg/m^2, Wind load acting on the building is 50 kg/m^2 for height below 10 m. and 80 kg/m^2 for height between 10-20 m.

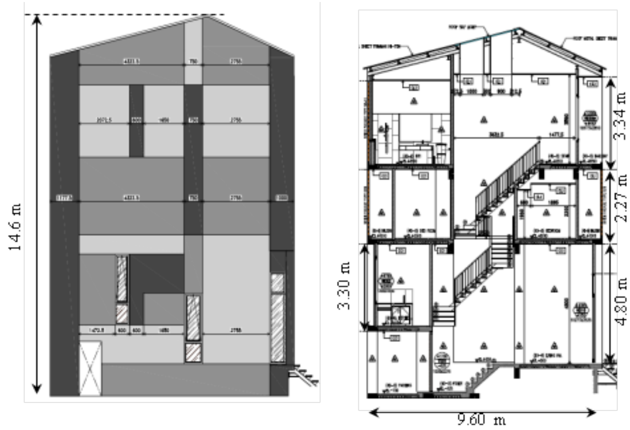

Figure 11 The prototype house for structural modeling

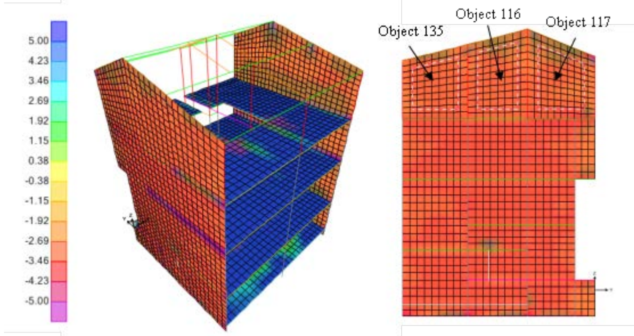

Figure 12 Maximum stress, ksc, on wall surface (C6)

For other loads, dead load was based on the element sizes shown in the construction drawing, temperature change and vibration load were already obtained from the measurement at site. Therefore, according to the measured data, the applied temperature change in the structural model would be 6.5°C; and for vibration load, the measured acceleration data was adopted to apply at the building base.

Totally, 6 load combinations were considered in the analysis as follows:

Combination 1 (C1) : DL + LL

Combination 2 (C2) : DL + LL + WL

Combination 3 (C3) : DL + LL + TC

Combination 4 (C4) : DL + LL + VB

Combination 5 (C5) : DL + LL + WL + TC

Combination 6 (C6) : DL + LL + WL + TC + VB

3.2 FE analysis results

From analysis of the structural model, only walls in 3rd floor of the building were considered as they represent walls of the light gauge steel column with the light weight block wall system. The considered walls on 3rd floor compose of 3 wall area objects, which are referred as area object 135, 116 and 117 as shown in Figure 12. In the figure, the results of the maximum stress on wall surface from simulation of the structural model are also presented for the load combination case C6, which is found to be the most severe case.

Table 3 presents the maximum and minimum stresses of the 3rd floor wall surface for all load combinations. The positive value represents the tensile stress while the negative means the compressive stress. It can be seen that, for all load combinations except C5, the maximum tensile stresses are mostly found on wall area object 117, which are 1.01, 7.7, 4.94, 3.98 and 7.54 ksc for case C1, C2, C3, C4 and C6, respectively. For load combination case C5, the maximum tensile stress of 6.62 ksc is found on object 116. This probably due to larger area of object 117 compared to object 116 and 135, which is subjected to larger applied loads than others. Moreover, the load combination cases including wind force (C2, C5 and C6) are found to have larger tensile stress than cases without wind (C1, C3 and C4). Therefore, it can be concluded that wind force is the main factor of stress occurs on wall surface.

If we compare the results of Tensile stress on wall surface with the highest bending stress capacity of joint connection obtained from previous test (6.43 ksc for connection Type 3), it can be obviously seen that the connection type 3 can sustain load in all cases except the case with wind force (case C2, C5 and C6) since the maximum tensile stress on wall is larger than the capacity of connection. Thus, it also means that wind force is the main reason which causes cracks on the wall (the light gauge steel column with the light weight block wall system). For other load combinations without wind force (case C1, C3 and C4), even the plain wall without any connection (Type 5) is strong enough to sustain the loads. Therefore, temperature change and vibration are not the main reason of cracks on wall surface.

The difference between the maximum stress on wall obtained from analysis (7.54 ksc on object 117 for case C6) and the bending stress capacity of the plain wall connection type 5 (5.16 ksc) can be calculated as 2.38 ksc which is about 46% of the type 5 wall capacity. Therefore, if the amount of connection type 3 which the bending stress capacity has been found to be increased about 25% of type 5 capacity is double applied, or triple of the wall connection type 1, it may be able to imply that cracks due to wind load can be prevented. The problem of cracks found on the light gauge steel column with light weight block wall shall be reduced.

Table 3 Analysis results of stresses (S, ksc) on wall surface from simulation

Load Combination	Area object 116		Area object 117		Area object 135	
	S Max	S Min	S Max	S Min	S Max	S Min
C1	0.68	-1.28	**1.01**	-1.27	0.83	-1.54
C2	3.03	-8.05	**7.70**	-9.04	2.46	-6.73
C3	2.08	-4.19	**4.94**	-7.53	2.28	-3.79
C4	0.91	-1.09	**3.98**	-4.25	0.48	-0.80
C5	**6.62**	-3.86	4.70	-10.33	2.48	-3.41
C6	6.64	-8.08	**7.54**	-10.48	5.69	-6.67

4. Conclusions

The experiments and analysis results for the stresses on walls of the light gauge steel column with light weight block wall system have been presented. Bending test experiments were performed on 5 types of joint connection between the light gauge steel column and the light weight block wall for obtaining the joint stress capacity. Peak particle velocity was measured for verifying vibration level at the real construction site. Acceleration and temperature were measured to obtain the data of the acceleration and the temperature change for using as input force in the FE analysis. Finally, FE analysis of the prototype house was performed to compare the stresses on wall with the stress capacity obtained from the experiments. The results show that

1. Joint connection using the metal strap has more strength or stress capacity than using the dowel bar. Applying wire mesh cover on the connection at joint in plastering work shall increase the stress capacity at joint. Therefore, the metal strap with wire

mesh connection is the most efficient connection compared to others.

2. External force that has most effect on the stresses on wall is wind force while the effect from vibration during construction on transportation or the temperature change is smaller.

3. Normal concrete block wall system without using the light gauge steel column has enough stress capacity for only load case of Dead and Live load. However, under combination of all load cases, double amount of metal strap with wire mesh joint connection (or triple amount of the dowel bar with wire mesh connection) is necessary for preventing cracks on the wall.

It can be concluded that wind is one of the main reason for cracks occur on the wall of the light gauge steel column with light weight block wall system. The dowel bar or the metal strap can be used as a joint connection of the light gauge steel column with the block wall, nevertheless, there must be enough amount of the dowel bar or metal strap in order to reduce and prevent cracks on the wall.

5. Acknowledgements

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