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Improvement of Assembly Equipment for Prefabricated Houses

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Abstract

Unlike in the conventional RC method, prefabricated houses are prefabricated in the form of unit modules at a factory and assembled at a site. At the site, a ratchet wrench or an electric impact wrench is used to assemble the unit modules; however, their work efficiency is low, and construction tools including wrenches can often cause hazards for workers. In this study, an improvement plan is proposed by analyzing the problems of the existing assembly tools to enable the safer and more efficient assembly of modules. Through a structural analysis of the improvement plan for the assembly tools, it was found that the potential maximum stress of the tools did not exceed the yield stress of the steel.

Keywords*: Pre-fabricated house, Modular Unit, Assembly Tool, Structural Analysis*

1. Research background and objective

The unit modules are prefabricated at a factory, transported to a construction site and then assembled as prefabricated houses through the assembling and connecting process [1]. The demand for prefabricated houses has been gradually increasing since 1992, when the industrialization of building systems was introduced [2]. However, to build prefabricated houses, the unit modules must be assembled and bonded. There are no specialized tools for prefabricated houses; for this reason, the work efficiency is low. As such, the work efficiency of assembling the modules and workers' safety are not considered sufficiently [3].

Unlike in the conventional RC method, about 60% to 80% of the entire construction process is done at factory in the form of unit modules. The prefabricated unit modules are transported by vehicle to and then assembled at a construction site. Prefabricated houses are completed by assembling diverse types of unit modules. The assembling and connecting method has many advantages, including cost reduction, reduction in construction duration, and improvement of seismic capacity, and it is widely used for the assembly of unit modules [4]. In particular, the assembling and connection of unit modules at the site assembly phase is an important process that has a direct impact on the safety and quality of a structure. Therefore, unit modules should be connected using a certain level of torque. However, when connecting columns or a column with a beam in the assembling work of unit modules, it is hard to secure sufficient working space for boltwork, which leads to a deterioration in the safety and quality of the prefabricated houses [5].

A torque wrench or an electric tool such as a corner drill is used to assemble unit modules at a construction site, but it is hard to employ such a tool in a small and uncomfortable space, reducing the work efficiency and creating a hazard for the workers [6]. Therefore, this study aims to clarify the problems of the existing assembly tools and present an improvement plan of assembly tools for prefabricated houses in order to achieve work efficiency and worker safety.

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2. Research Methodology and Scope

In this study, to improve the assembly tools for prefabricated houses, the current state of torque wrench and electric tools used to assemble unit modules was first investigated, and the potential problems that might occur in the use of electric tools identified. Next, by analyzing the problems, an improvement plan for the assembly tools were prepared, not only to complement the shortcomings of the tools but also to improve worker safety. Third, a simulation was implemented for the tool developed in this study, by performing a structural analysis to secure its structural safety and to optimize the tool for the assembling work.

This study is restricted to the container-box shaped structures composed of square-shaped steel pipes and H-shaped steel of diverse types of prefabricated houses that have been frequently built in recent years. As such, interior and exterior finishing materials and other facilities are not included in the application scope of the assembly tool developed in this study. In addition, the assembly tool was designed to be used to assemble or disassemble unit modules, or a unit module with the foundation.

3. Current State of Assembly Tools for Unit Modules

In assembling unit modules for a conventional prefabricated house, manual tools including the ratchet wrench shown in Figure 1(a) are used. However, it is almost impossible to perform the assembling work within a certain range of torques in reality, which means that the boltwork has an adverse impact on the safety and quality of the structure. The length of the ratchet wrench makes it difficult to work with a ratchet wrench if an insufficient working space is secured. The ratchet wrench is transformed as shown in Figure 1(b) for the work done in a small space, such as the space between modules or between a module and the foundation. But while the L-shaped ratchet wrench enables a worker to work in a small space, it is unable to convey as much force as a ratchet wrench does.

An electric wrench, which is shown in Figure 1(c), is used for the parts on which a high-quality boltwork needs to be performed rapidly. The electric wrench has the assembling performance with a constant level of torque. Compared with manual tools, the boltwork can be done relatively faster. However, it has the impact function that provides a certain level of torque or higher, and the length and the diameter are larger compared with manual tools.

(a) Ratchet wrench | (b) L-shaped Ratchet wrench | (c) Electric impact wrench

Figure 1. Existing Assembly Tools

Boltwork is needed between modules, between a module and the foundation, and between a module and the roof. For this reason, an assembly tool is used for the boltwork, which poses a threat to the laborer who works in a small space as shown in Figure 2(a), or at a higher space. Electrical tools can be used since manual tools have relatively low work efficiency and are not conducive to improving worker safety. However, the electric tool is not appropriate for the size of steel used for unit modules, and its use is limited, as illustrated in Figure 2(b).

(a) Work in a small space

(b) Work that prohibits the use of electric impact wrench

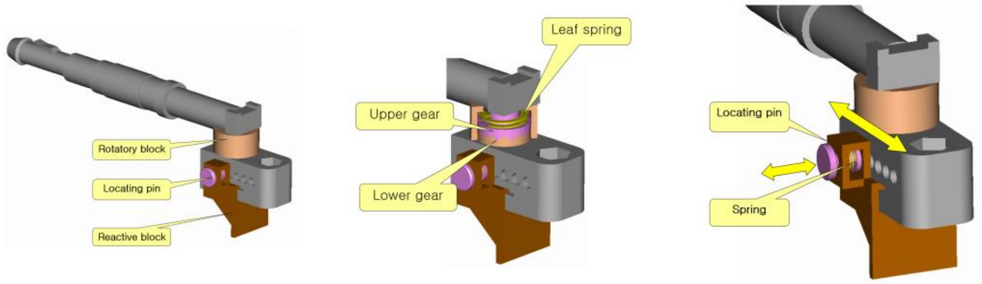
Figure 2. Problems with Existing Tools

In sum, it is impossible to perform the boltwork at a certain level of torque with the existing ratchet wrench. In addition, the boltwork is greatly affected by the working space, and if performed on the second floor or higher, the worker is vulnerable to safety issues. There are some spaces where an electric wrench cannot be used due to its physical dimensions. Therefore, the tool developed in this study for the assembly of unit modules should address these problems.

Taking into account the problems of assembly tools mentioned in Section 3, the assembly tool is designed to address the issue of low work efficiency and worker's safety. Also, a worker can perform the boltwork at a small space to assemble the unit modules, and the torque performance should be secured at a certain level or higher. Moreover, the structural safety needs to be verified after considering a load-transfer behavior analysis related with the load and stress generated from the assembly tool in the boltwork.

To improve work efficiency and increase worker safety, various tools were examined. Of these, an air wrench was selected since it enables a worker to perform the boltwork in a small space but its performance is deteriorated if it is used for a long time. While a general air wrench has good torque performance, it has a relatively longer body compared with other tools, which results in low usability in small spaces. For this reason, a geared offset was provided to enable a worker to perform the boltwork even in a small space. A reactive block was installed to counter the reaction generated at a higher torque to improve worker safety.

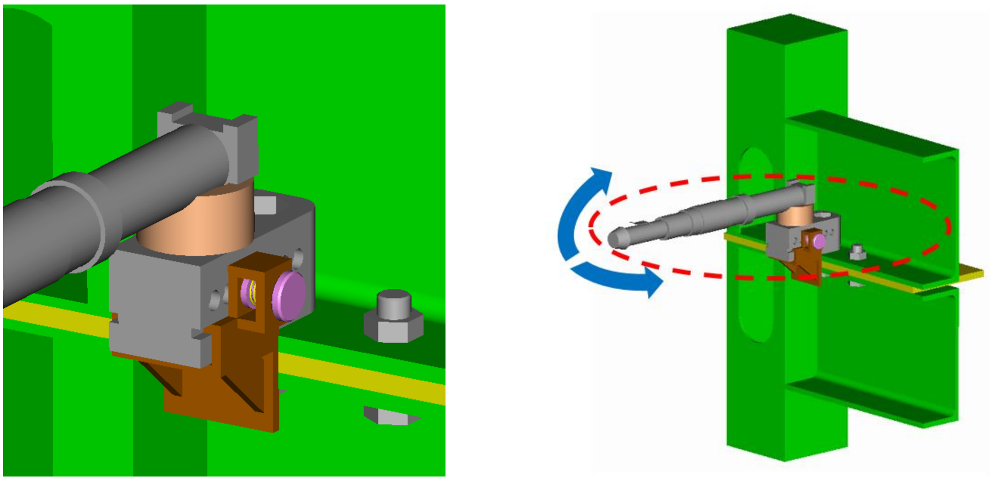
The geared offset for the improved assembly tool largely consists of a reactive block and a rotary block, as shown in Figure 3(a). The rotary block changes the direction of the air wrench when a sufficient working space cannot be secured, to enable a worker to perform the boltwork in a small space. In a composition, a leaf spring is used to make turning easy. The upper gear and the lower gear were arranged in a sawtooth form to endure the torque generated during the boltwork, as shown in Figure 3(b). The reactive block counters the reaction to ensure the minimum reaction is delivered to the worker. There is a groove on the geared offset, and the position of the reactive block can be adjusted and fixed by using a locating pin depending on the dimensions of the steel on which a bolt is connected, as shown in Figure 3(c).



(a) An improvement plan for an assembly tool (b) Rotary block (c) Reactive block

Figure 3. Structure of Improved Assembly Tool

Figure 4(a) illustrates that the reactive block is on the coupling beam by adjusting a locating pin to connect the bolt and the coupling beam. Figure 4(b) shows how to change direction by using the rotary block after the assembly tool developed in this study is on the place to be bolted.



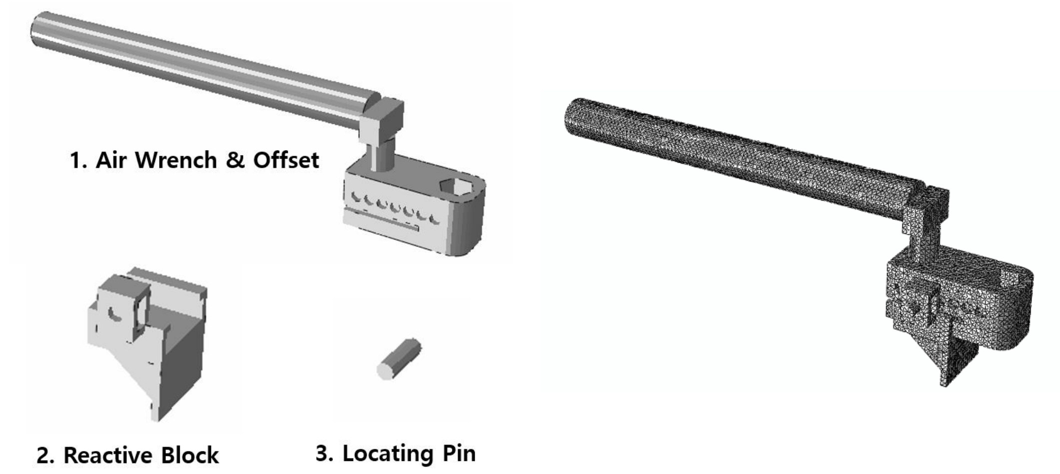
(a) Adjustment of the rotary block (b) An example of using a rotary block

Figure 4. Adjustment of the Assembly Tool and an Example of Using a Rotary Block

5. Performance Verification through a Nonlinear Structural Analysis

In this section, the load behavior of the assembly tool developed in this study was analyzed through a nonlinear finite element analysis to verify the structural safety of the new tool. The maximum stress was calculated through a nonlinear finite element analysis when applying the maximum torque of 325N.m to the combination of the air wrench, the rotary block, the geared offset, the reactive block and a locating pin, and then its safety was confirmed.

As illustrated in Figure 5(a), the assembly tool developed in this study was divided into three parts: air wrench & geared offset, reactive block and locating pin, to compose the FEM (Finite Element Method) model. It is assumed that the air equipment and the rotary block are incorporated as one, and the air equipment and the rotary block were simplified because no load is imposed on them. The general contract conditions provided by ABAQUS were entered for each of the boundary sides since the components are connected with one another. Figure 5(b) is a combination of the three components of the FEM model, and the Mesh shape was processed using 3D triangular pyramid factors for the analysis.



(a) Components of the FEM model (b) FEM Model and Mesh shape

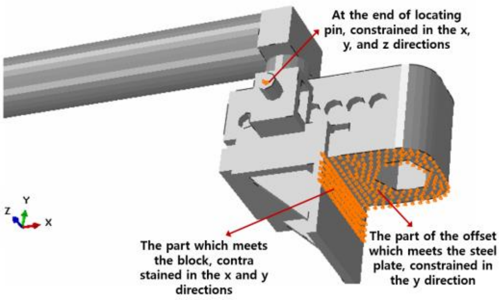
Figure 5. FEM Model for the Improved Assembly Tool

For the analysis, the materials for the components of the FEM model were set as SS41 Steel. Table 1 indicates the mechanical properties of SS41 Steel. The friction coefficient between steel and steel was hypothesized as 0.6.

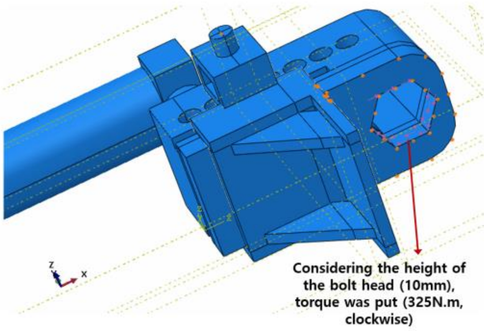
Table 1. Mechanical Property of SS41

Division	Value
Yield strength (f_y)	240 MPa
Tensile strength (f_u)	400 MPa
Deformation rate (ϵ_u)	0.1
Coefficient of elasticity (E)	210,000 MPa
Poisson's ratio. (ν)	0.3

Figure 6 (a) shows the boundary conditions of the analysis model. Both x- and y-displacements were constrained at the contact between the reactive block and the steel plate, while x-displacement was constrained at the contact between the offset and the steel plate. Lastly, the rigid body behavior was prevented in the model by constraining x-, y-, and z-displacements at the end of the locating pin. Figure 6(b) shows the load conditions of the analysis model. The head of a bolt is put in the offset and then turned. When it is turned, torque is generated. Considering the height of the head (10mm), torque is set to occur clockwise by applying shear force on the contact between the bolt and offset. The torque was set at 325N.m of the maximum torque of the air wrench.



(a) Boundary conditions of the analysis model



(b) Load conditions of the analysis model

Figure 6. Conditions of the Analysis Model

Figure 7 shows the Von-Mises stress distribution of the entire model consisting of three components. Von-Mises stress can be expressed as uniaxial state of stress equivalent to the multiaxial state of stress so that a member can be evaluated simply by using yield stress in the form of uniaxial state of loading. As shown in Figure 7, strong stress (approx. 215Mpa) appeared locally at the point where the reactive block and the geared offset met.

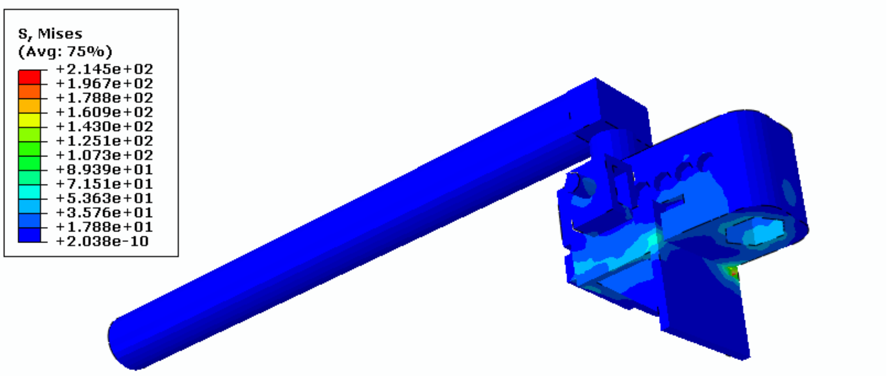
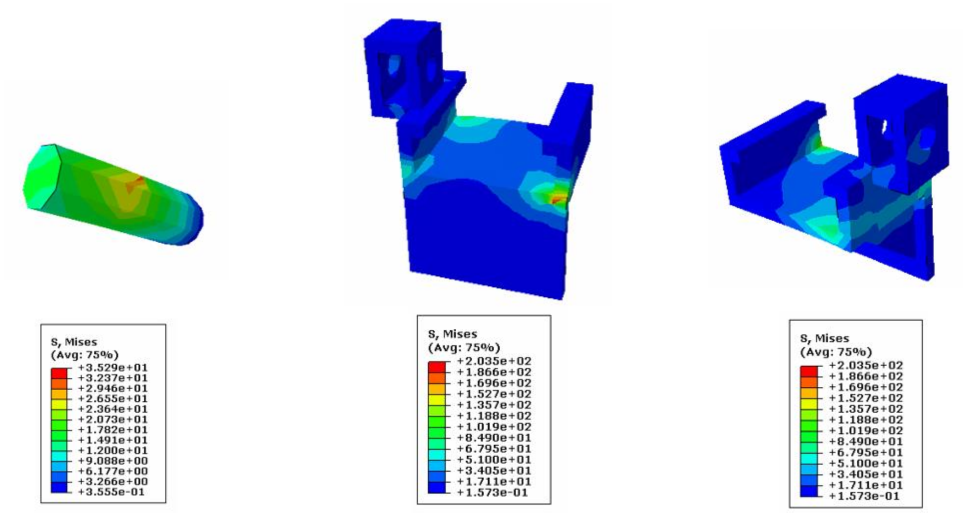


Figure 7. Von-Mises Stress Distribution of the Entire Model (325Nm)

In terms of the maximum stress distribution generated on each part (Figure 8), the maximum stress on the reactive block was about 204MPa while that on the locating pin was about 35MPa. In addition, it was found that high stress was shown at the diagonal ends on which reactive torque was formed. Except for the parts with high stress, overall Von-Mises stress was shown between 51MPa and 143MPa. It is believed that a maximum torque of up to 325N.m can be used with this model.



(a) Locating pin (b) Reactive block-1 (c) Reactive block-2

Figure 8. Von-Mises Stress Distribution by Part (325Nm)

Figure 9 illustrates the floor surface of the geared offset on which the maximum stress was generated. The yield stress of the steel used in the analysis was 240MPa. The maximum stress did not exceed 240MPa, but the stress was relatively higher compared with yield stress. However, in the FEM, stress concentration was found to be generated on the edges on which two right-angle sides meet. In an actual building, the edges are expected to have the radius of curvature or weld neck, and thus this stress concentration might decrease.

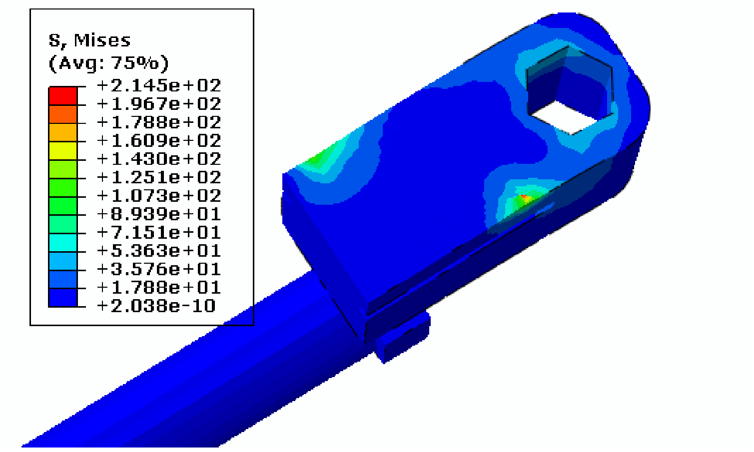


Figure 9. Von-Mises Stress Distribution of the Geared Offset (325Nm)

6. Conclusion

This study improved assembly equipment for unit modules of a prefabricated house in order to secure worker safety and improve work efficiency. The improvement plan for assembly equipment was composed to address the weaknesses found in the ratchet wrench and the electric impact wrench, which are the main tools used in conventional assembly. It is impossible to do boltwork at a certain torque with the existing manual tools. In addition, the boltwork is greatly affected by the working space, and poses a hazard for workers at higher stories. Moreover, boltwork sometimes cannot be performed due to space limitations. To address these problems, an air wrench with geared offset was proposed as a component of an improvement plan. Also, reactive and rotary blocks are included in the improvement plan, and the problems reported from the existing tools can be resolved.

The structural safety of the improvement plan for assembly equipment was verified through a nonlinear finite element analysis. For the analysis, the equipment was divided into three parts: air wrench & offset, reactive block, and locating pin. When the maximum torque of the air wrench (325Nm) was applied, a strong stress of 215MPa was measured on the floor surface of the offset. This did not exceed the yield stress of 240MPa, and it appeared that the new plan can endure the load at site.

The improvement plan for assembly equipment proposed in this study is expected to improve the work efficiency of boltwork performed in small spaces and secure worker safety by addressing the shortcomings of the tools generally used in prefabricated house assemble, the ratchet wrench and the electric impact wrench.

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