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Lab-based Simulation of Carton Clamp Truck Handling - Preliminary FEA and Analysis of Handling Test Courses

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Abstract Carton clamp truck is widely perceived as the high-efficient handling equipment of factory premises and warehouse by its capability of palletless handling. Therefore, the significance of a lab-based handling simulation is becoming higher with the growth of clamp truck usage. In this study, preliminary FEA and design of handling test courses for the lab-based simulation of carton clamp truck handling were performed, and the PSD analyses were performed for the modified one for the test course proposed by Park et al. (2017) as well as ASTM D 6055 and ISTA 3B standards. For the vibration in all directions, the vibration energy intensity analyzed by ISTA 3B standard showed higher than that by the other two cases. A FEA was performed for the handling operation of the sudden stop of the clamps after lifting the target HCP (heavyweight refrigerator corrugated package, w=180 kgf) up to the specified height. The slip distance between the clamp arm and the target HCP was 0.85 mm. The simulation result of 0.85 mm was 3.7 times lower than the experimental result (3.2 mm) obtained by Park et al. (2017), and it was estimated that the deviation comes from both the experimental error by weight imbalance of target HCP, and excessive simplification during the FE modelling of target HCP.

Keywords Carton clamp truck, Carton clamp truck handling, Carton clamp truck handling simulation, Finite element analysis, Handling test course

Introduction

The use of carton clamp trucks in the distribution system is becoming more popular and the need to properly simulate its handling in a distribution testing laboratory will become increasingly important[1].

Palletless handling is growing in popularity as warehouse managers struggle to reduce costs and increase storage space[2]. Carton clamps are forklift attachments that allow users to quickly handle unitized loads without the requirement of pallets, and provide easy and efficient handling of non-pallet based loads in both factories and warehouses. Some examples include cartons, foods, chemical products, fruit and vegetables or other boxed cargo in warehouses, beverage, appliance and the electronics industries. Accordingly, carton clamps allow for the optimization of warehouse storage space and reduction of packaging material costs[2-4].

In carton clamp truck handling, the load must be able to withstand the pressure of being clamped. This is the biggest factor of using carton clamps. The load is very crucial to the method as it can crush the product if not stable enough. Therefore, the problems of determining the optimum clamping pressure and the right size clamp arm are very important.

The study about carton clamp truck handling simulation is rare. Stewart et al.[5] made a Power Spectra Density (PSD) profile by measuring the vibrations that occured during warehouse handling and truck loading, and then they designed a clamping-force simulation device (consisting of vibration table, forklift mast, appliance clamp, hydraulic input station, etc.) using the PSD profile to reproduce the handling environment and its associated required clamping force. Although the device successfully simulated the vibration environment for warehouse handling conditions, it did not completely reproduce the vibration condition for the truck-loading environment because of the shock duration pulse that occurred during the truck-loading process.

Experimental studies on carton clamp truck handling have recently been conducted by some researchers. Park et al.[6] developed a numerical model for determining the theoretical minimum clamping pressure required in carton clamp truck handling of heavyweight corrugated package (HCP) such as refrigerator packages. To develop the model, the dynamic load

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factor was measured at the handling test course which designed on the basis of actual handling environment of the target HCP, and a static-frictional coefficients between the HCPs and between the HCP and a rubber contact pad of carton clamp arm were analyzed. The main factors in the developed numerical model of clamping pressure were the handling load weight and the effective contact area of the carton clamp arm. Through field test, they suggested that analytical approach using a numerical model would be very useful in estimating the clamping pressure of the carton clamps which used to handle the HCP. Spencer et al.[7] reported that a minimum horizontal spacing of 7.62~10.2 cm between unit loads was required to accommodate the physical dimensions of the carton clamp. They also mentioned that this disadvantage in space efficiency restricts transformation from typical pallet-based handling to pallet-less load handling by the carton clamp. Singh et al.[8] analyzed the effects of the ride height, measuring position and stacking patterns of unitized loads on shock intensity, load retention and load containment of unitized loads in the carton clamp truck-handling environment using two handling test protocols of ASTM D 6055[9] and ISTA 3B[10], and demonstrated that there was no significant correlation between stacking patterns for the shock intensity according to obstacle course, ride height, measuring position and drivers. Peter[11] focused on the clamping structure itself and the forces required to handle a paper roll without causing physical damages on it.

The purpose of this research was to perform preliminary FEA and design of handling test courses for the lab-based simulation of carton clamp truck handling, and specific research objectives are as follows:

1) to analyze PSD for each handling course of carton clamp truck.

2) to analyze the difference between the methods by conducting the finite element analysis (FEA) on the experimental results of Park et al.[6]

3) to study the procedure and the method of lab-based simulation of carton clamp truck handling through FEA.

Analysis of Handling Test Courses and Preliminary FEA

1. Clamp Truck Handling Test Courses

Two main lab-based testing standards available to simulate mechanical handling using carton clamp truck are ASTM D 6055 - test method C[9] (or ISO 10531[12]) and ISTA 3B[10].

ASTM D 6055[9] provides a clamp handling test procedure that involves a standard course and test method designed to determine the ability of the shipping unit (unitized load, large shipping case, or crate, etc.) to withstand clamp truck handling. The L-shaped course of ASTM D 6055[9] includes 3 to 3.5 m wide aisles with a 90° turn, approximate acceleration/deceleration zones, and observation points (OP 1 through OP 5). Speed of clamp truck should not exceed 1.5 m/s (walking speed) at user-defined test zone, and is about 1 m/s in turning. A typical example of obstacle includes two nominal 2.54 by 15.24 cm pieces of lumber, beveled on both top edges at 45º, secured to the floor in a staggered pattern.

The procedure for the ASTM D 6055[9] handling course proposed by Singh et al.[8] is as follows;

1) to locate the clamp truck with the unitized load approximately 18.3 m from the two wooden obstacles in OP 1

2) to set the load down and pick up the load as flat off the ground as possible. The center of the load must be in line with the center of the clamp arms

3) to pick up the unitized load to the appropriate load height

4) to measure the unitized load in the back, middle and front in reference to the top of the driver side clamp pad

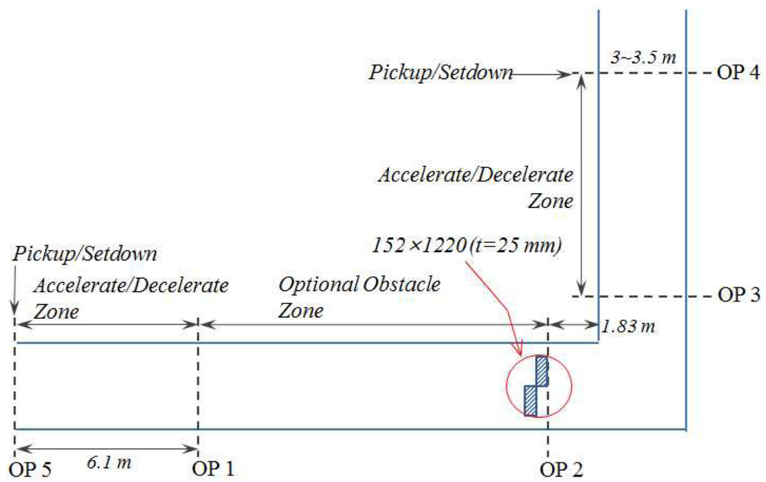


Fig. 1. Recommended handling course layout for carton clamp truck in ASTM D 6055[9].

5) to establish a velocity of approximately 1 m/s using the 1 m tape lines on the ground

6) to proceed over the plate obstacles while maintaining a velocity not exceeding 1 m/s

7) after the clamp truck passes the last wooden obstacle (OP 2), to turn 90° to the left and accelerate back to approximately 1 m/s and then decelerate to a stop at OP 4

8) to measure the unitized load in the back, middle and front in reference to the top of the driver side clamp pad.

9) to set the unitized load down

The ISTA 3B[10] handling course is not intended for carton clamp truck handling, but rather, it is designed to simulate the effects of mechanical handling using a conventional fork truck apparatus. The ISTA 3B[10] handling course have 10~11 steel or wooden plate obstacles of three types, and all sharp edges of obstacles should round.

The procedure for the ISTA 3B[10] handling course proposed by Singh et al.[8] is as follows;

1) to locate the carton clamp assembly approximately 9.14 m in front of the last plate obstacle A

2) to set the unitized load to the ride height

3) to measure the unitized load in the back, middle and front in reference to the top of the driver side clamp pad

4) to establish a velocity of approximately 1 m/s using the 1 m tape lines on the ground

5) to proceed over the plate obstacles while maintaining a velocity not exceeding 1 m/s

6) to stop the clamp truck after the rear wheel has cleared the last plate obstacle A

7) to reverse the clamp truck and to proceed over the plate obstacles backwards until the clamp truck returns to its original starting position

8) to measure the unitized load in the back, middle and front in reference to the top of the driver side clamp pad.

9) to set the unitized load down

In case of HCP such as refrigerator packages, there are some limitations to accurately simulate carton clamp handling using the previous test protocols such as ASTM D 6055[9] and ISTA 3B[10] because these protocols do not consider shocks occurred by the height difference between trucks (trailers) and loading docks during loading and unloading operation. In addition, they do not reflect the sudden stopping of the clamping arm after lifting heavy loads vertically when multi-stage stacking in warehouse and the lateral force to the load generated by the turning of the clamp truck. Thus, Park et al.[6] suggested new handling test course of carton clamp truck in study about numerical analysis of clamping pressure during carton clamp handling of heavyweight corrugated packages. The hazards in the handling test course include the clamp truck driving movement (forward and backward), height difference between the loading dock and the trailer, the turn-around movement of the clamp truck and sudden stop movement after lifting the HCP up to the required height for multi-stacking.

2. FEA for the experimental results of Park et al.[6]

Park et al.[6] analyzed the dynamic load factor at handling test course proposed by them by selecting a large refrigerator package (weight: 1,760 N, dimension: L×W×D = 1003×980×1880 mm) as the target HCP. As a result, the highest dynamic load factor was reported to be derived from the suddenly stop motion after lifting the HCP up to the specified height. Therefore, the FEA was performed to evaluate this harzardous operation that suddenly stops after the sudden rise of the HCP.

ANSYS (Ver. 14.5, ANSYS Inc., USA)[13] was used as a pre- and postprocessor in FEA. Fig. 4 shows the FEA models

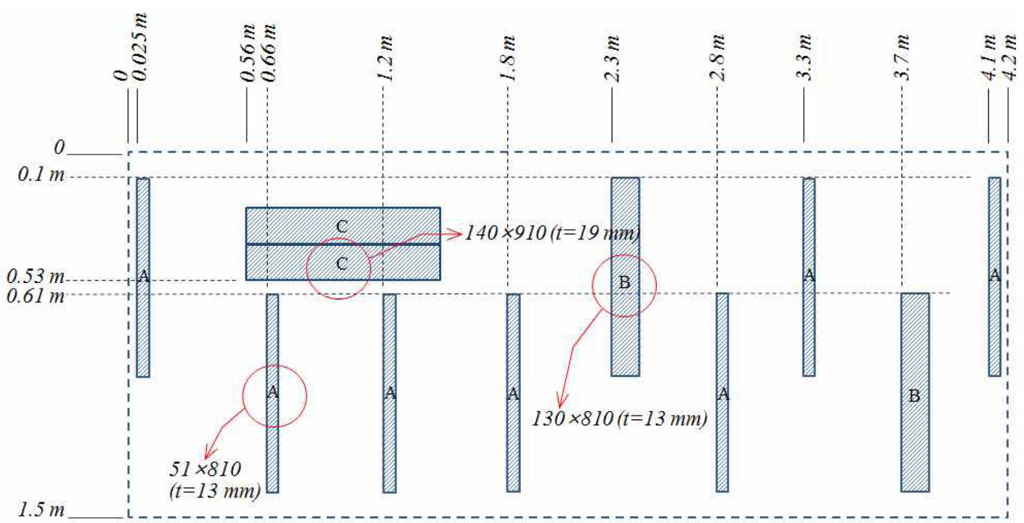


Fig. 2. Recommended handling course layout for fork truck in ISTA 3B[10].

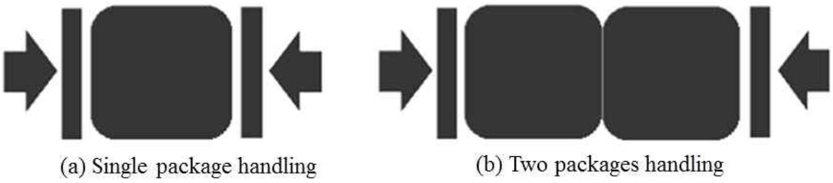


Fig. 3. Schematics of carton clamp handling method for the target HCP.

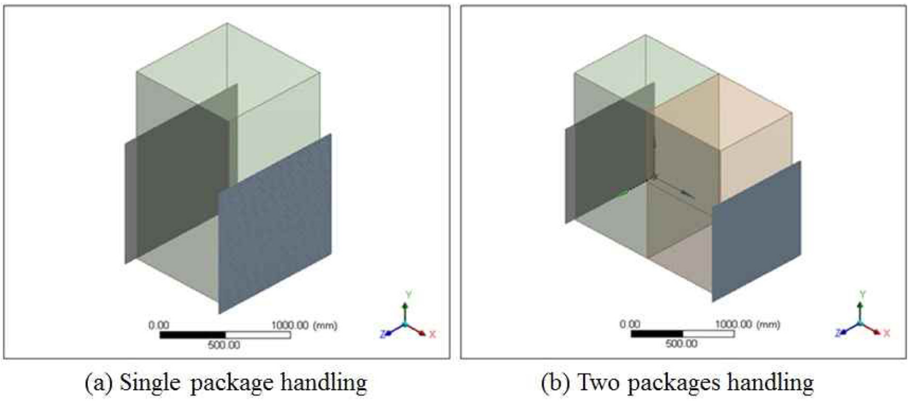


Fig. 4. FEA models for each handling methods of the target HCP; (a) single package handling and (b) two packages handling.

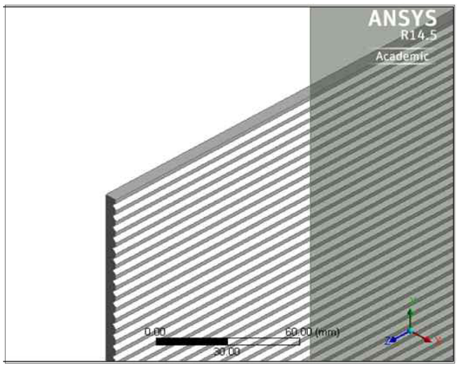


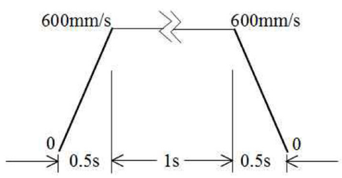
Fig. 5. FEA model of the rubber contact pad of the carton clamp arm.

for each handling methods of the target HCP in Fig. 3 and 5 shows the FEA model for the rubber contact pad of carton clamp arm.

The frictional force between the clamp arms and the HCP is a function of the clamping force and the frictional coefficient between the two, and the clamping force in carton clamp handling is ruled by the law of action and reaction (Newton's third law). During the FEA, the effect of the stiffness of the corrugated paperboard was ignored for the simplification of modelling. In addition, the target package (weight: 1,760 N, dimension: L×W×D = 1003×980×1880 mm) consisted of a product and packaging materials was considered as a rigid body and modeled using 3D solid elements (SOLID 186). The rubber contact pad was also modeled using 3D solid elements (SOLID 186) with an isotropic material properties (Young's modulus: 8×10^{6} Pa, Poisson's ratio: 0.3)[13].

To accurately represent the testing conditions, the frictional coefficients between the rubber contact pad and the target HCP and between the target HCPs were employed in the FEA, and only the clamp arm was allowed to move parallel to

Table 1. Conditions applied to the FEA

Package	Clamping pressure[6]	Velocity profile of clamp arm
- weight_180 kgf - size_1003×980×1880 mm - outer liner_KLB175	- 3.85 kPa for Fig. 4(a) - 7.69 kPa for Fig. 4(b)	

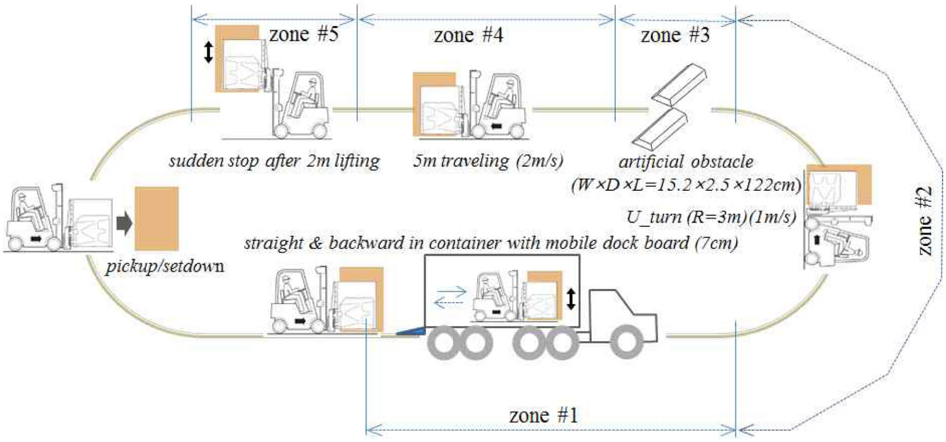


Fig. 6. The modified one for the test course proposed by Park et al.[6].

the y-axis, while its'movements in the x- and z-axis were constrained as illustrated in Fig. 4 and 5. On the other hand, the movement of the target HCP was not limited for all-direction.

The simulation sequence of lifting operation consisted of three steps as shown in Table 1. Velocity increases (acceleration) from 0 to 600 mm/s for 0.5 s (step 1), maintaining the velocity (uniform motion) for 1 s (step 2), and the velocity decreases (deceleration) from 600 mm/s to 0 for 0.5 s (step 3). The velocity data were obtained from the standard specifications of the hydraulic cylinder mounted to the carton clamp truck[14]. During this simulated sequence of lifting operation, the total lifting height of the carton clamp arm was estimated as 900 mm (150 mm for step 1 + 600 mm for step 2 + 150 mm for step 3). Even though the lifting height is less than the working lift height (3~6 m) of carton clamp, this lifting height of 900 mm can be regarded as acceptable because the relative displacement which means a slip distance between the carton clamp arm and target HCP primarily is mostly occurred by the sudden movement at acceleration (step 1) and deceleration (step 3) where the carton clamp arm experienced a velocity change. The relative displacement or slippage was analyzed at the four bottom corners of the target HCP, and the average slip distances were compared with the experimental results of Park et al.[6].

Results and Discussion

1. PSD Analysis for Various Clamp Truck Handling Test Course

The power spectral density (PSD) was frequently employed to measure and analyze vibration impact during truck (or trailer) transportation of products. A typical PSD function (G^2/Hz) describes the strength of the vibration energy as a function of the frequency. Overall G-rms is the square root of the integral of PSD over the total frequency range, and represents the vibration energy intensity for the entire frequency region[15].

By using PSD profile measured from the HCP while the clamp truck is driving, it is technically feasible to determine the frequency range of dominant vibration impact. In addition, PSD profile could be employed to simulate the handling environment of a clamp truck in laboratory scale.

The PSD profiles for the two existing test coures[9,10], including the modified one (Fig. 6) for the test course proposed by Park et al.[6]. were analyzed. Fig. 7~9 show the PSD profile for each test course, and Table 9 shows overall G-rms for each of them.

In case of very low frequency, the vibration energy intensity in the Z_axis (vertical direction) was larger than that in the other two directions in all test courses. However, as the frequency increased, the virbration energy intensity in the X_axis (longitudinal direction) was somewhat larger than that in the other two directions. For the vibration in all directions, the

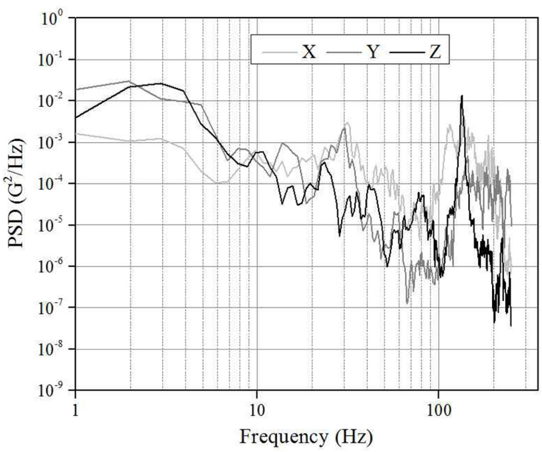


Fig. 7. The PSD profiles measured on the clamp truck handling test course of ASTM D 6055[9].

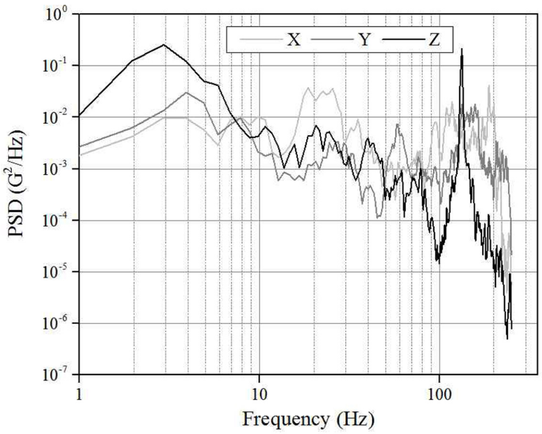


Fig. 8. The PSD profiles measured on the fork truck handling test course of ISTA 3B[10].

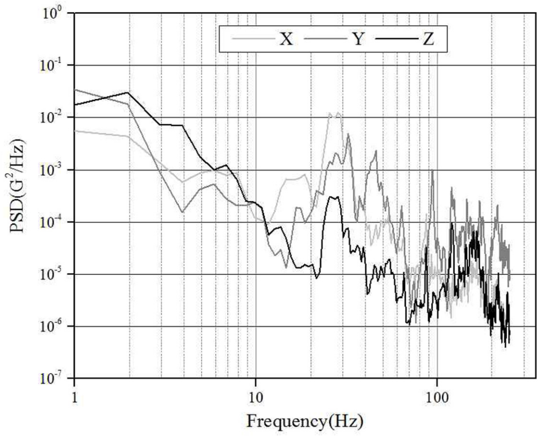


Fig. 9. The PSD profiles measured on the clamp truck handling test course in Fig. 6.

Table 2. Overall G-rms of PSD profiles measured from various clamp truck handling test courses

ASTM D 6055[9]	ISTA 3B[10]	Test course in Fig. 6
- X_axis : 0.3445 - Y_axis : 0.3259 - Z_axis : 0.3633	- X_axis : 1.1710 - Y_axis : 0.8652 - Z_axis : 1.1957	- X_axis : 0.3132 - Y_axis : 0.3279 - Z_axis : 0.2674

Table 3. Specific data applied to the FEA

Frictional coefficient		Density of package
contact pad~package	package~package	
0.78	0.26	180/(1.003×0.980×1.880) = 97.41 kg/m^3

vibration energy intensity analyzed by ISTA 3B[10] standard showed higher than that by the other two cases.

2. FEA for the experimental results of Park et al.[6]

A FEA was performed using the theoretical minimum clamping pressures at the handling operation of the sudden stop of the clamps after lifting the target HCP up to the specified height. FEA was performed by applying the friction and clamping pressure values (Table 1 and 3) to FEA models shown in Fig. 4.

As shown in Fig. 10, the slip distance between the clamp arm and the target HCP was turned out to be 0.85 mm for both single package handling and two package handling through FEA. Based on the FEA results, we consider that the slip distance is almost negligible compared with the overall load-lifting distance of 900 mm.

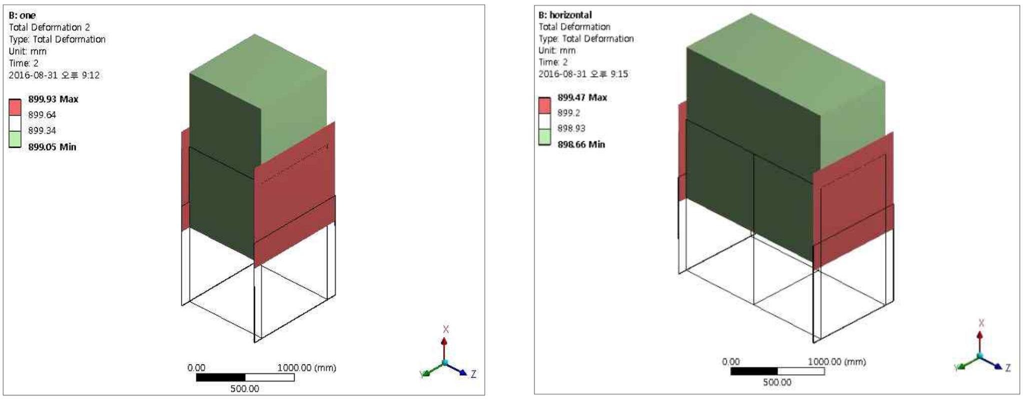
Park et al.[6] have reported the average slippage between the clamp arm and the HCP through an actual test was 3.2 mm (measured at four bottom corners of target HCP) for the handling motion by lifting the target HCP by 2 m and then stoping it (applying the clamping pressure in Table 1).

Slippage estimated by FEA was 3.7 times lower than that from the field test. This discrepancy was due to forward tilting motion of the target HCP caused by the weight imbalance; i.e., the center of gravity of the target product was actually closer to the front of the product rather than the geometrical center considered in FEA. In addition, the shear stress occurred during the carton clamping process at the flutes of the corrugated fiberboard in the target HCP, and this shearing effects can cause more vertical slippage. Therefore, considering these factors appeared in the actual test at the FEA, it could be possible to reduce the difference from the experimental value.

This FEA was for one of many harzard elements constituting the clamp truck handling course. Actual clamp truck handling, however, takes place in a continuous environment of many harzard elements. Therefore, for the lab-based handling simulation of clamp truck through FEA (Fig. 11), the following points should be clarified or considered.

1) Corrugated package consists of product, cushioning material and corrugated paperboard; therefore, FE modelling for each component should be performed, and mechanical characteristics for each component should be applied in FEA.

2) In the vibration evaluation of clamp truck operations, the three-axes vector synthetic problem should be significantly



(a) Single package handling (b) Two package handling

Fig. 10. The results of FEA for slip distance between the clamp arm and the HCP; (a) single package handling and (b) two packages handling of the target HCP.

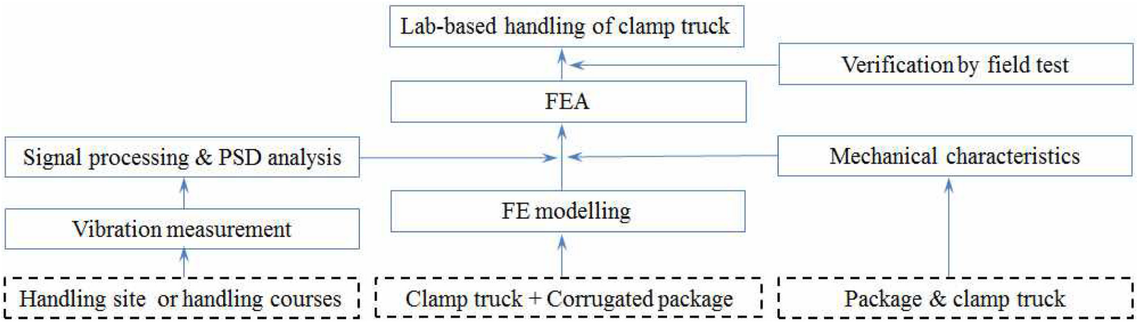


Fig. 11. Procedure for lab-based handling simulation of clamp truck.

considered because vibrations from both longitudinal and lateral direction are substantial compared to that of vertical direction.

3) Both the tire types (solid or air type) and driving speed need to be considered during the development of PSD profile through the vibration measurements.

4) PSD profile can be simplified by the linearization of statistical distribution using the significant break points of frequencies.

Conclusions

Recently, several efforts have put on to reduce the use of wooden pallet because of the depletion of forest resources and environmental issues. Under these circumstances, a carton clamp truck is being commonly considered as the high-efficient handling equipment with its capability of palletless handling. Therefore, the significance of a lab-based handling simulation is becoming increased by the use of clamp truck. In this study, preliminary FEA and design of handling test courses for the lab-based simulation of carton clamp truck handling were performed. The summary of the results is as follows.

1) PSD analyses were performed to compare the modified one for the test course proposed by Park et al.(2017) with ASTM D 6055 and ISTA 3B standards.

2) For the vibration in all directions, the vibration energy intensity analyzed by ISTA 3B standard showed higher than that by other two test courses.

3) A FEA was performed for the handling operation of the sudden stop of the clamps after lifting the target HCP up to the specified height. The slip distance between the clamp arm and the target HCP was 0.85 mm. The simulation result of. The simulation result of 0.85 mm was 3.7 times lower than the experimental result (3.2 mm) obtained by Park et al.(2017), and it was estimated that the deviation comes from both the experimental error by weight imbalance of target HCP, and excessive simplification during the FE modelling of target HCP.

4) We described the procedure and major considerations needed for the lab-based handling simulation of clamp truck for its whole load and unload test course.

Acknowledgments

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