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Abstract

This study focuses on the critical loads of scaffolding with the anchor rods, plank and inner knee brace under concentric and eccentric loads during construction. The steel rebar is used in place of the patent anchor rod in this research. This study shows that the critical load of the scaffolding increases by 1.5 times when the anchor rods of length of 30 cm are used on two sides of every story of scaffolding. The critical load increases by 4 times when the scaffolding has both anchor rods and plank. The critical load of scaffolding with the anchor rods placed on each story is twice as large as the load with anchor rod added every two stories. In addition; the failure mode of the structure is also transformed from the in-plane direction to the out-of-plane direction. The 30 cm long anchor rod, a steel bar of grade 3, provides a good lateral restraint to the scaffolding. The setup plank can significantly increase the critical load of the scaffolding. The critical load increases by 1.5 times under the concentric load, and increases up to 2.2 times under the TL/4 eccentric load defined as the load applied a quarter distances from the end. The anchor rods and the planks are suggested to install in a scaffolding to improve stability, especially under eccentric loads during construction.

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1. Introduction

During the construction, scaffolds are frequently used as the working scaffolding system erected at the external circumstance of the building under construction. Door-shape steel-pipe scaffolds are widely used in construction sites. Fig. 1 shows the basic assembly of the door-shape steel-pipe scaffolding system used in construction.

The feature of scaffolding system includes the single-row assembly model with cross-brace removed at the side nearer to the façade of a building.

In construction, wall scaffolds provide a good working platform for workers for assembling and disassembling of formworks and stuccoing works, etc. According to a recent survey of construction sites, it was found that the anchor rods connecting scaffolds and façade of buildings do not have a proper installed method. The grade 3 rebar of diameter equal to 3/8 in, 0.9525 cm and nominal design strength 275 N/mm^2, is substituted for the patent anchor rod in construction sites. Furthermore, during stuccoing and finishing process of buildings, anchor rods are even frequently removed for the purpose of working convenience.

The wall scaffold needs to be paved with plank for working operation. Since the wall scaffold is installed in a single row for the convenient setting of formwork or finishing works for facades so that the lateral side adjacent to the constructing building has no cross-brace in the construction stage as shown in Fig. 1. The set plank should be able to enhance the critical load of a scaffolding system and strengthen the weak point of having no cross-brace as well. This scale of its enhancement should be studied.

Previous study by Godley and Beale (1997) indicated that the behavior of system scaffolds involved the windward standard to uplift forces relative to the horizontal load. Peng et al. (2008) revealed the effect of simple eccentric loads to the scaffolding systems without considering the plank and anchor rod. Most research on scaffolds (Peng et al. 2001, Yu 2004, Weesner et al. 2001) involved the strengths of shoring systems. These studies were not related to the scaffolding systems for finishing works.

This research investigates the critical loads of scaffolding systems under concentric and eccentric loads for probing into the effect of use of the anchor rod and the plank. The type of research mainly emphasizes on the test and analysis. The outlines of this research can be classified as the following five categories: (A) the structural behavior of the basic setup scaffold, (B) the effect of anchor rod to the critical load, (C) the effect of plank to the critical load, (D) the effect of both anchor rod and plank to the critical load, (E) the effect of inner knee brace to the failure model.

The analysis presented in this study is based on a three-dimensional second-order elastic analysis using semi-rigid joint. The analysis software adopted here is GMNAF program developed by Chan (1988). For simulating the initial imperfection of the scaffolding system, the notional lateral force is applied to the structure in the analysis. This lateral notional force is approximated as 0.1~0.5% of the factored gravitational load.

2. Material Properties

The type of the tested scaffold used in this research is the door-shape steel-pipe scaffold with inner diagonally reinforced bracing bars, i.e. knee braces, shown in Fig. 2. The sectional dimensions of the scaffolding structural members adopted here are mainly in compliance with the requirement of Chinese National Standard (1996). Fig. 2 indicates all the dimensions of the vertical columns, horizontal bars and cross-braces.

All members are made of carbon steel in compliance with CNS requirement with the Young modulus of elasticity E for the analysis taken as that of the standard steel material or 20006.3 kN/cm^2 (2040 tonnes/cm^2). The joint stiffness of the scaffold obtained from the previous test is 784.6 kN-cm/rad (80 tonne-cm/rad) (Peng et al. 2004) and this stiffness for joints in the connecting scaffolds is applied as the basic reference data for analysis in this paper.

3. Setup of Test

3.1 Setup of Scaffold

At the assembly of the testing scaffold in Fig. 3, the adjustment base with its base-plate cut-off is placed at the bottom of the scaffold. The adjustment jack base without base-plate placed on 4 pieces of iron sheets can simplify the bottom boundary condition of scaffolding system as a “hinge” in the analysis. The conditions of top layer and the lowest layer scaffold are similar so that the top boundary conditions are also assumed as “hinge” in the analysis. The top boundary condition of the scaffolds is to prevent any lateral displacement since four horizontal restraints are fixed to prevent the top H-beam frame from horizontal movement. Thus, the scaffold can only provide vertical movement under load.

3.2 Scaffold with Anchor Rod and Plank under Eccentric Load

In the loading test, the scaffold is installed upside down. Two pieces of steel plates are placed at the bottom of each vertical column of scaffold. Further, between the two steel plates, 9 steel balls are installed as a cross-frame window shape; i.e. 3 balls are provided at each of the 3 rows equally spaced. This type of erection enables the part in contact with the floor which is movable when the scaffolding system is subjected to the vertical load. This installation is mainly for simulating the movable top level of the scaffolding system.

Fig. 4(I) indicates the movable situation of the shoring system. However, the top load P of the laboratory hydraulic system is placed as shown in Fig. 4(II). Since the position of the hydraulic system is fixed, the hydraulic punch head expands freely in mono-direction. Therefore, the simulating lateral displacement of scaffolding top end is not directly available. In this research, for simulating the lateral boundary displacement, the method of erection shown in Fig. 4(III) is applied.

The letters L, R, T, B shown in Fig. 5(I) represent the locations Left, Right, Top and Bottom respectively. In Fig. 5(I), "Center" indicates the central location of the applied load with respect to the xy coordinate lying on (d/2, L/2). T/4 is the eccentric load shown in Fig. 5(II) with the load placed at the position (d/2, 3L/4) of the xy coordinate. L/4 eccentric load is located at (d/4, L/2) of xy coordinate shown in Fig. 5(III). In TL/4 eccentric loading test, the load was applied at asymmetric location along upper & lower and left & right directions, i.e. at the location (d/4, 3L/4) of xy coordinate shown in Fig. 5 (IV). All of the 4 types of eccentric loading tests are separately processed with the two types of erection as single-side cross-brace with the removal of cross-brace at the access location.

4. Discussions of Test and Analysis

4.1 Structural Behavior of Basic Setup Scaffold

The basic setup scaffold is defined as the restrained boundary with no lateral displacement and under a concentric load. The critical load of the basic setup scaffold is considered as a basis for comparison with the other scaffolding cases. The averaged critical load of the 2-story scaffold with cross-brace at both sides is 117.7 kN. The averaged critical load for the 2-story scaffold with only one single-side cross-brace is 102.9 kN. The averaged critical load for the 3-story scaffold with cross-brace at both sides is 104.1 kN. The averaged critical load for the 3-story scaffold with cross-brace at only single side is 70.2 kN. From the aforementioned test result of basic scaffolds, it is found that the second or repeated loading test results of the four groups are reduced for more than 40%. Therefore, it is known that the effect of the variation between brand new and worst used and old scaffolds to their critical load is enormous.

4.2 Effect of Anchor Rod

The tests in this research adopt a No. 3 rebar as an anchor rod to connect scaffolds. Two types of connections are respectively 45 and 90 degrees to the scaffold. As shown in Fig. 5(I), the angle of the anchor rod is defined as 90 degrees. Due to the feature of temporary accessory, anchor rods in construction sites are frequently connected in a slight inclination. As it is taken as 45-degree connection in this research, it is deemed as the worst connection. The 90-degree connection is the standard connection angle and is deemed to be the best connection of the anchor rod.

During the test, the applied loads are the concentric load and the TL/4 eccentric load. It is intended to check the effectiveness of anchor rod to critical load of the scaffold under the eccentric loading condition. The 2-story scaffold is tested with the cross-brace of the lowest story of scaffold removed.

4.2.1 Test Result

A. Concentric Load

• *Without Anchor Rod*

The test without anchor rod is carried out for comparing with the strength of scaffolding structure with anchor rod and plank. Owing to limited space of testing facilities and widely practiced fastening the anchor rod in every 2-story scaffold, the test applies 2-story scaffolding structure in two types of installation as follows: (1) the scaffolding system with removal of cross-brace at access location [Type (1)] and (2) the scaffolding system with only one single-side cross-brace [Type (2)].

Fig. 6 indicates the deformed shape of the loaded scaffolding system after the test where the cross-brace of the bottom story are removed and this arrangement is denoted as Type (1). There is no restraint at the top story, i.e. the testing bottom story, of the scaffold so that apparent displacement occurred at failure. The averaged critical load of the test is 35.7 kN.

The number of cross-brace of scaffold is more than that of Type (1) scaffold so that the critical load of Type (2) is higher than that of Type (1). The averaged critical load of Type (2) is 62.0 kN. In the tests, no restraint is applied at the top story, i.e. the bottom level of the tested scaffold, of the scaffold so that significant displacement occurred at failure. The failure style of Type (2) is similar to that of Type (1).

• *90 Degree Anchor Rod [Type (1)]*

The length of anchor rod is 30 cm and it connects the scaffold by coiling twice on vertical column of the scaffold. A concentric load is applied to the scaffolding system where the cross-brace at the bottom story of the scaffold is removed as well.

As the top story (i.e. the bottom story of the tested specimen) of the scaffold is restrained by the anchor rod so that the deformation becomes small here. The critical load of the test is 56.5 kN which, compared to the unrestrained condition 35.7 kN, is observed to have greatly increased.

• *45 Degree Anchor Rod [Type (1)]*

The 45 degree erection is similar to the 90 degree erection. The 45 degree is defined as anticlockwise rotation of the anchor rod from the original vertical direction as shown in Fig. 5(I). The deformation of the scaffold after the load is similar to that of 90 degree. However, the averaged critical load is reduced to 44.3 kN. The ratio of the two cases of 45 and 90 degrees is 0.78 (=44.3/56.5). This indicates that the 45 degree erection has longer length to scaffold than that of 90 degree erection in Fig. 5(I) so that this reduces the critical load of the 45 degree scaffold.

B. TL/4 Eccentric Load

• *Without Anchor Rod*

This test without the anchor rod is also applicable for comparison of the critical loads of scaffolding systems with the anchor rod and the plank. With the exception of TL/4 eccentric load, the setups of tests are the same as the case for concentric load. It means the test is processed by using 2-story scaffolding structure under 2 types of erection as follows: (1) the scaffolding system with removal of cross-brace at access location as Type (1), and (2) the scaffolding system with only single-side cross-brace as Type (2).

As Type (1) has its bottom story cross-brace removed, its critical load is rather low. The averaged critical load is 18.1 kN. The averaged critical load of the Type (2) scaffolding system with single-side cross-brace is 32 kN. Compared with the concentric load condition, the critical load of Type (2) is reduced by approximately half as 0.51(=18.1/35.7) and 0.52 (=32/62), respectively. It indicates that the joint of the scaffolding system under TL/4 eccentric load generates a greater extent of damage, which greatly reduces the critical load of the scaffold.

• *45 Degree Anchor Rod [Type (1)]*

This research adopts TL/4 eccentric load in simulating the worst eccentric load condition of the scaffolding system in construction sites. The system is a 2-story scaffold with the removal of cross-brace at access location. The anchor rod is applied with inclination θ equal to 45 degree connecting the scaffold as shown in Fig. 5(I). The test result indicates the critical load as 32.9 kN

The averaged critical load of the scaffolding system having 45 degree erection of anchor rod is 32.9 kN. Compared with the critical load of 44.3 kN with 45 degree anchor rod scaffold under concentric load, the critical load of 32.9 kN is rather low. The ratio of the two is about 0.74 (=32.9/44.3).

However, it is quite close to the critical load 35.7 kN of the scaffolding system without anchor rod and under concentric load. This indicates that after the scaffold is fixed with 45 degree anchor, its restraining effect drops about 25% when compared with 90 degree connection. Nevertheless, when compared with the scaffold without anchor rod and under concentric load, the boundary condition can be transformed from laterally movable to unmovable conditions making the effect of TL/4 eccentric load insignificant.

4.2.2 Analysis of Anchor Rod Stiffness

The research mainly implements a 2-story scaffolding system where the anchor rod is taken as linearly elastic spring providing elastic stiffness as ks (=*EA/L*). If the anchor rod length taken as *L*=30 cm and the elasticity modulus as E = 20012.4 kN/cm^2 (a nominal value of steel) are adopted for the analysis, the rebar stiffness is varied by simply changing its cross-sectional area A, i.e. changing the rebar diameter.

The analysis result is shown in Fig. 7. When the diameter is increased to No. 3 rebar diameter 0.9515 cm, the stiffness of anchor rod k_s = 475.1 kN/cm and the analyzed scaffolding critical load is 89.5 kN as shown in Fig. 7. The Figure further indicates that when the anchor rods diameter is 0.2 cm, i.e. at k_s = 21 kN/cm, the analyzed scaffolding critical load is close to 89.5 kN. Therefore, it is found that if 30 cm long No. 3 rebar is applied as anchor rod with wide use of this No. 3 rebar in construction sites, the bending behavior of the rebar can be neglected. This implies that if the rebar is properly fixed to the scaffold, it can provide the lateral restraint to the scaffold in prevention of the lateral displacement.

4.3 Effect of Plank

4.3.1 Test without Anchor Rod

A. Concentric Load

A scaffolding system having the single-side cross-brace and with the plank placed every story is the most popular and basic practice in construction sites. Deformations of the scaffold all occur in the in-plane direction of the scaffolding system at the first or oirgin load in the concentric loading test. The average critical load of the scaffolding system is 94.2 kN in tests. Further, the failure of the overall scaffolding system appears to have a slight rotation. The average critical load of the scaffold with plank and single-side cross-brace is increased by a factor of 1.5 (=94.2/62.0) times, compared with the scaffolding system without plank.

B. TL/4 Eccentric Load

Under TL/4 eccentric load, the test result shows that the failure of the scaffolding system occurs in the in-plane direction and the deformation is located near the loading position. This failure style is similar to the scaffold with the same installation process under the concentric load. The average critical load of the eccentric load scaffolding system is 70.6 kN. Compared with the erection without plank, the average critical load of the scaffolding system with plank increases by 2.2 (=70.6/32.0) times. Therefore, it is found that setup of plank has a very good effect in increasing the critical load of the scaffolding system.

4.3.2 Analysis of Plank Connecting Types

This paper analyzes the connected effect of the plank to the critical load of the scaffolding system on the basic of the test results. The analysis is based on the 4 types of loads: i.e. the concentric, L/4 eccentric, T/4 eccentric and TL/4 eccentric loads shown in Fig. 5. In the analysis, the laterally movable top layer is adopted for its similarity to the case for real construction sites. Since the bottom story of the scaffolding system is not provided with jack bases, it is deemed to be a hinged joint for the conservative design. The connections between the plank and the scaffold are considered as three cases, namely as hinged joint, rigid joint and semi-rigid joint with spiral elastic stiffness equal to 490.5 kN-cm/rad.

Fig. 8 shows the analysis results based on the planking ends, fastened by hinged joint under different eccentric loads. It is found from the various planking ends, hinged joints, rigid joint and semi-rigid joint, that the connection stiffness between the planking end and the scaffold has insignificant effect to the critical loads of overall scaffolding systems. Under the same loading conditions, the critical loads of the scaffolding systems with 2 to 12 stories vary only slightly. This is quite close to the observations in another publication that the scaffolding systems under the various eccentric loads without plank (Peng et al. 2008).

If the worst condition of the planking end connection is applied, the planking end is assumed to connect to the scaffold with the hinged joint. In this case, the analysis results are compared with the critical loads of the scaffolding systems with and without the plank. The comparison is shown in Fig. 8 using the data from reference (Peng et al. 2008). Fig. 8 reveals that the critical loads of the scaffolding systems concentrated at two regions though various eccentric loads are taken into consideration. The region is divided into areas with the plank and without the plank.

As shown in Fig. 8 and under concentric loading condition, the scaffolding system with plank increases the critical load for 2.7 (=60.9/22.4) times. Under T/4 eccentric loading condition, the critical load is increased by 2.6 (=44.9/17.8) times. Under L/4 eccentric loading condition, the critical load is increased by 3.5 (=51.1/14.7) times. Under TL/4 eccentric load condition, the critical load is increased by 3.3 (=40.9/12.3) times. From the analysis results shown in Fig. 8, it is found that if a scaffolding system is installed with the plank, the critical load of the scaffolding system can dramatically increase twice. The added plank can make up the partially lost strength of the scaffolding system when the single-side cross-brace is removed. Therefore, the plank should not be removed from the working scaffolding system in construction sites.

4.4 Effect of Both Anchor Rod and Plank

This paper analyzes the effect of the simultaneous setup of the plank and the anchor rod in scaffolds to the critical load of the scaffolding system. In addition to installing the single-side cross-brace and the plank in every story, anchor rods are also installed on both sides of every 2-story of the scaffolding systems for analysis of scaffold from 2 to 12 stories. The boundary condition is the same as the one in construction site condition. Hinged connections are assumed between the anchor rod and the scaffold. The connections between the plank and the scaffold remain the same, respectively as hinge joint, rigid joint and semi-rigid joint. Their spiral elastic stiffness is 490.5 kN-cm/rad.

Fig. 9 shows the analysis results of hinged joint of planking ends under different eccentric loads. From the test results being very close to each other in the end stiffnesses, hinged joints, rigid joint and semi-rigid joint, it is found that the connection stiffness between the planking end and the scaffold has insignificant effect to the critical load of the scaffolding system furnished with planks and anchor rods. This is similar to the analysis results of the planked scaffolding system without the anchor rod described above.

If a weak hinged joint is used as the connection for the planking end, Fig. 10 shows the analyzed strengths of scaffolding systems with and without the plank and the anchor bar. Fig. 10 indicates several results. To illustrate this, a 12-story scaffolding system is taken as the example.

(1) Under concentric loading condition: the critical load of the scaffolding system with both the plank and the anchor rod is approximately 1.5 (=89.0/60.9) times of that of the scaffolding system with plank but without the anchor rod. Furthermore, it increases 4 times (=89.0/22.4) when compared with the critical load of the scaffolding system with the anchor rod but without the plank.

(2) Under TL/4 eccentric loading condition: the critical load of the scaffolding system with both the plank and the anchor rod is approximately 1.4

(=57.1/40.9) times of the scaffolding system with the plank but without anchor rod. Moreover, it increases 4.6 (=57.1/12.3) times compared with the critical load of the scaffolding system with the anchor rod but without the plank.

This paper shows that under TL/4 eccentric load, the properly fastened anchor rod can approximately increase the critical load of the scaffolding system by 1.5 times. If properly installed for both the plank and the anchor rod in the scaffolding system, the critical load can be increased by more than 4 times. Therefore, neither the plank nor the anchor rod should be removed from a working scaffold in construction site. The arbitrary removal of the plank or the anchor rod would considerably reduce the critical load of the scaffolding system.

4.5 Effect of Inner Knee Brace

4.5.1 2-story scaffold with Anchor Rod and Plank

The failure of the scaffolding system with the plank and the anchor rod is unique since the damage mostly occurs at the part of the scaffold below the first anchor rod. This paper studies the effect of inner knee brace of the scaffold on the critical load of the scaffolding system.

Fig. 11 indicates the deformation of a 6-story scaffolding system with the anchor rod and the plank before and after loading. Anchor rods are setup in every 2-story height in this system. Fig. 11 shows that the deformation occurs mostly at the 2-story scaffold measured from the ground level. This scaffolding system does not deform above the level of the first anchor rod. Additionally, the deformation merely occurs in the in-plane direction of the scaffold whereas there is almost no deformation in the out-of-plane direction. Additionally, considering the 4-story scaffold without the inner knee brace, its deformation is shown in Fig. 12. It is close to the failure model in Fig. 11.

4.5.2 Stiffness Effect of Anchor Rod

If the linear elastic stiffness of the anchor rod varies, the changes of the scaffolding system within and without inner knee brace can be studied. Fig. 13 indicates a 4-story scaffolding system, when the horizontal elastic stiffness of the anchor rod changes to 21 kN/cm, i.e. when a rebar 0.2 cm diameter is used, the critical load of the scaffolding system is 89.5 kN and that of the portal frame is 52.2 kN. Also, as shown in Fig. 13, the critical loads of the scaffold and portal frame systems do not totally increase in line with the increment of the anchor rod stiffness. The critical loads of two systems respectively approach a certain fixed value.

4.5.3 Scaffold with Anchor Rod and Plank in Every Story

This paper studies the effect of installing anchor rod in every story to the critical load. The analysis and comparison are made for the scaffold and the portal frame system, i.e. scaffold without inner knee brace, from 2 to 5 stories. Fig. 14 shows the analysis result of the 4-story systems with the anchor rod at every story where all analysis assumptions are the same as above, except with the installation of anchor rods. It is found in Fig. 14 that, regardless of having inner knee brace or not, the failure mode changes from the original in-plane direction to the out-of-plane direction. Since the installation of the anchor rod in every story caused a change in the failure mode so that the effective length is reduced. This makes the critical load of the scaffold systems within and without the inner knee brace unrelated to the installation height of the scaffolds. Moreover, the strengths of the two systems with the anchor rod in every story are higher than those in scaffold with anchor rod placed every 2 stories.

Fig. 15 shows the analysis result of scaffolding system within and without inner knee braces from 2 to 5 stories. It is found from Fig. 15 that the critical load of the scaffolding system within the inner knee brace with every story installed with the anchor rod is 165.5 kN. Compared with the scaffolding system having anchor rods installed in every 2-story, the critical load approximately increases by 1.8 (= 165.5/89.5) times. It is also known from the figure that the critical load, 162.9 kN, of the scaffold not using the inner knee brace is slightly less than that of the scaffolding system with the inner knee brace. This discrepancy is not like the analysis result for the two cases where anchor rods are used in every 2-story of the scaffold.

5. Conclusions

- Based on this study, the critical load of the 2-story scaffolding system can increase by 1.5 times compared with that of scaffolding systems without anchor rods. The anchor rod of No. 3 rebar of 30 cm length is assumed in the studies. If both the No. 3 rebar and the plank are setup, the critical load of the scaffolding system can even increase by 4 times. While construction works is in progress, the plank and the anchor rod should not be removed.
- The plank can significantly increase the critical load of the scaffolding system when under the concentric load, the critical load increases by approximately 1.5 times, and when under TL/4 eccentric load, it is increased by 2.2 times. In addition, the failure deformation does not generate any lateral displacement in the out-of-plane direction like the scaffolding system without the plank whereas the failure shape occurs in the in-plane direction. Therefore, the installed plank in construction sites should not be removed when work is in progress.

- The critical load of the scaffolding system with the anchor rod in every story is about 2 times compared with the anchor rod installed in every 2-story height. The failure model shifts from the in-plane direction towards the out-of-plane direction. Also, since the effective length is fixed, the critical loads of different stories of scaffolding systems are rather close.
- The inner knee brace can provide additional stiffness so that if every 2-story scaffold is fastened with the anchor rod, the failure model is simply controlled by the failure of the lowest story.

6. Acknowledgments

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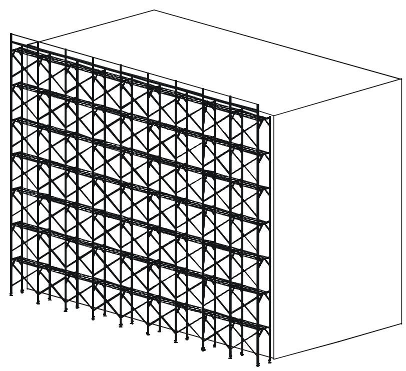
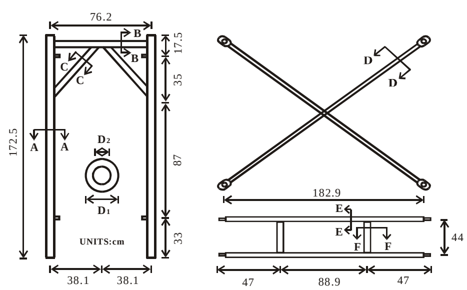


Fig. 1 Setup of steel scaffold for finishing near façade of building



cross section	D_1(cm)	D_2(cm)	A(cm^2)	I_y(cm^4)	I_z(cm^4)
A-A	4.27	3.77	3.157	6.403	6.403
B-B	4.27	3.77	3.157	6.403	6.403
C-C	2.72	2.32	1.583	1.265	1.265
D-D	2.17	1.77	1.238	0.607	0.607
E-E	4.27	3.77	3.157	6.403	6.403
F-F	3.40	2.94	2.291	2.892	2.892

Fig. 2 Dimensions of scaffolding unit, plank and cross-brace

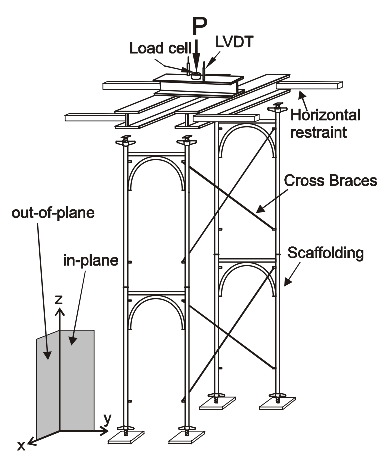


Fig. 3 Basic setup of scaffolds in loading tests

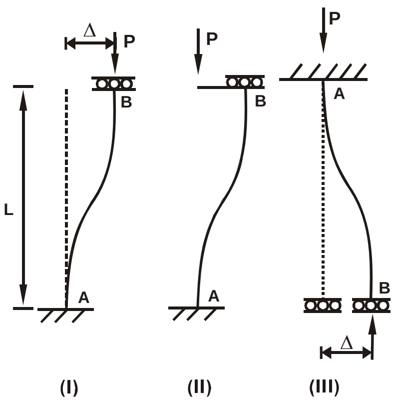


Fig. 4 Boundaries of lateral displacement of tested scaffold

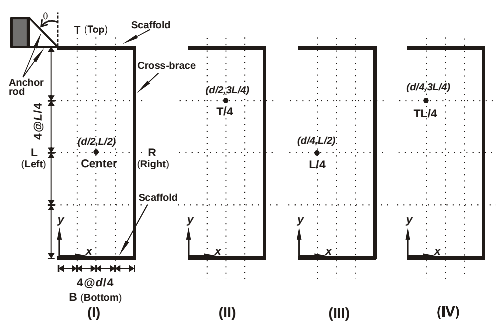


Fig. 5 Setups of loading positions and anchor rod in eccentric loading tests

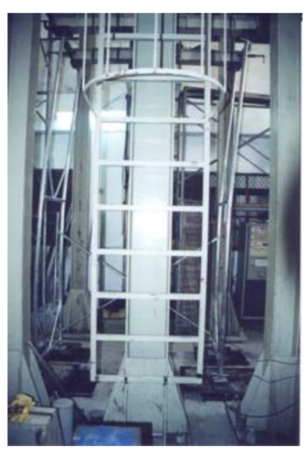


Fig. 6 Test result of scaffolds with removal of cross-brace at access location under concentric loading

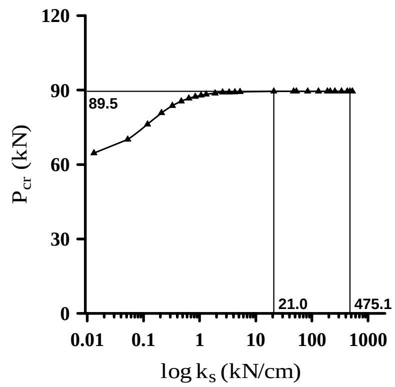


Fig. 7 Critical loads of stiffnesses of anchor rods for 2-story scaffold

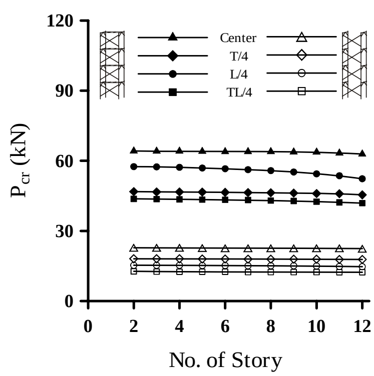


Fig. 8 Analyzed critical loads of scaffolds without and with plank using hinged connection under different eccentric loads

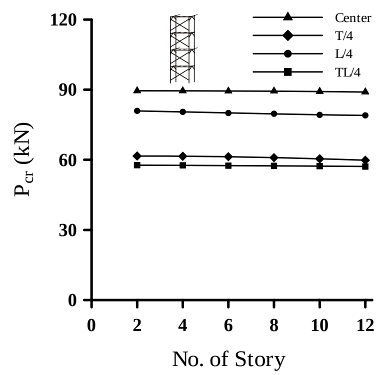


Fig. 9 Analyzed critical loads of scaffolds with anchor rod and plank using hinged connection under different eccentric loads

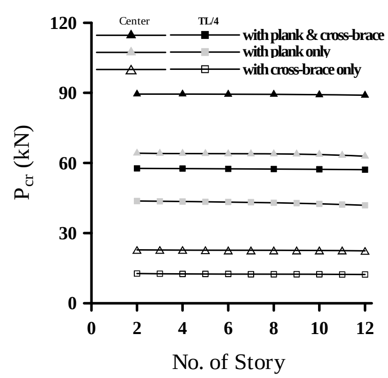


Fig. 10 Analyzed critical loads of scaffolds with and without anchor rod and plank under concentric and TL/4 eccentric loads

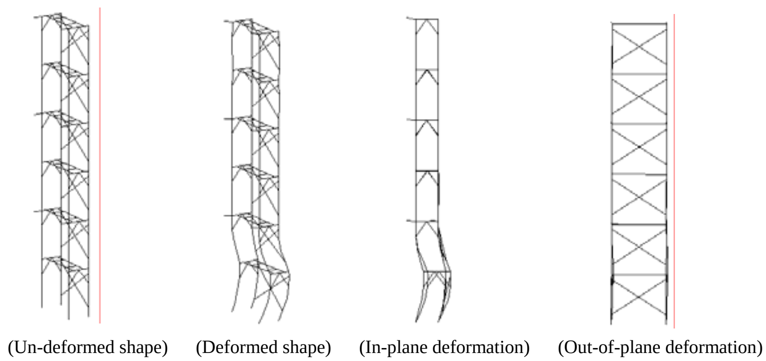
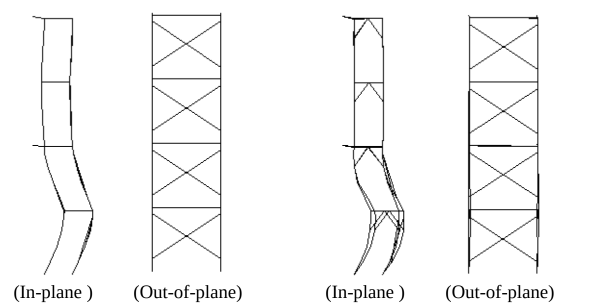


Fig. 11 Analysis results of 6-story scaffold with anchor rod and plank under concentric load (P_{cr}=89.4 kN)



(a) Without knee brace (52.2 kN) (b) Within knee brace (89.5 kN)

Fig. 12 Analysis results of 4-story scaffolds within and without inner knee brace after loading

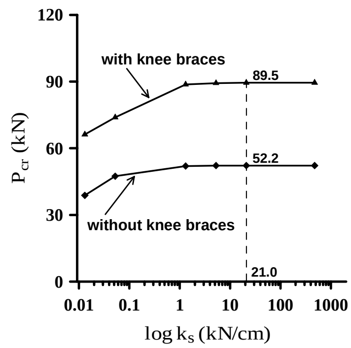
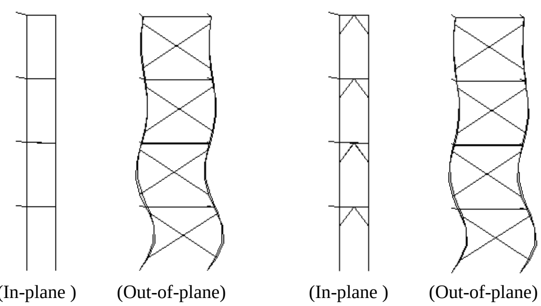


Fig. 13 Analyzed critical loads of 4-story scaffolds with stiffnesses of anchor rod every two stories and within and without inner knee brace



(a) Without knee braces (162.9 kN) (b) With knee braces (165.5 kN)

Fig. 14 Analysis results of 4-story scaffolds with anchor rod every story and within and without inner knee brace after loading

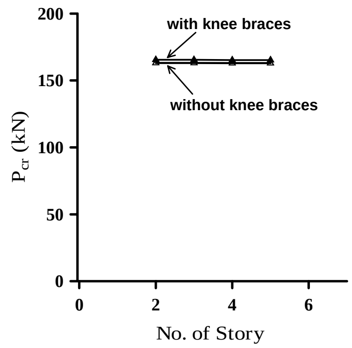


Fig. 15 Analyzed critical loads of scaffolds with anchor rod every story based on within and without inner knee brace