Mechanical Properties of a Self-Walking Sinking Platform for Ultra-Deep Shaft Sinking

Bo Wang*, Zhi-qiang Liu, Xing-fu Li, Zhi Liang, Hao Fan
School of Mechanics and Civil Engineering; State Key Laboratory for Geomechanics and Deep Underground Engineering, China University of Mining and Technology, Xuzhou 221116, China
** Corresponding author: wangbocumt@163.com*

ABSTRACT

A new hydraulic self-walking sinking platform (HWSP) has recently been developed for ultra-deep shaft construction. In order to ensure the structural reliability of the HWSP, it is imperative to carry out study on the mechanical properties of the HWSP before getting into practical application. In this paper, series of numerical and physical model tests were conducted to clarify the mechanical performance of the new sinking platform under two working conditions: fixed load condition and moving load condition. The results show that, under various working conditions, this new HWSP has a good structural safety and reliability, and it can be used for future deep shaft construction.

KEYWORDS: Deep shaft; Sinking platform; Hydraulic self-walking; Mechanical property; Reliability

INTRODUCTION

In shaft construction, sinking platform is hauled by sinking hoists and is the main underground working stage for shaft construction, on which sinking apparatus, such as loading grab, water tank, drainage pump and template were placed. Researchers and engineers have accumulated rich experience on design of the sinking platform through the past shaft constructions [1-3]. However, it is well known that self-weight of ropes increase with the increase of sinking depth. When the sinking depth of a shaft exceeds 1000 m, weight of the sinking platform added the increased self-weight of ropes are near or even larger than the capacity limitation of existing suspension ropes [4].

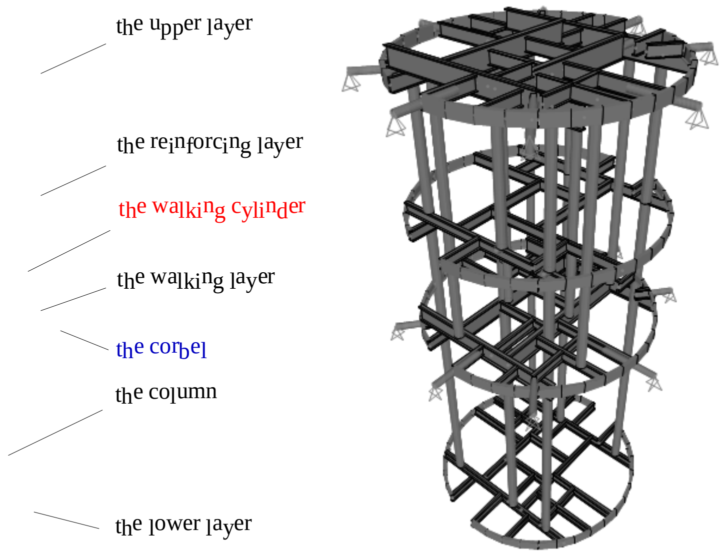
Hanging the sinking platform has become one of the key factors which restrict construction of a 1000m-plus deep mine shaft.

So far several researchers and engineers have tried different ways to deal with this problem [5]: developing high-performance sinking hoists and ropes; improving the hanging method and mode, etc. Liu et al. first proposed a hydraulic walking sinking platform (WMP type), which is hanged on the shaft wall by the reserved grooves and moved up and down by the hydraulic cylinders [6]. Zuo used similar approach to develop a moving hydraulic metallic template in the shaft wall construction [7]. Wang analyzed the structure selection and mechanical properties of sinking platform by considering the latest sinking technology and equipment. Series layout and structure selection of sinking platform were proposed with sinking depth 1200 m [8, 9]. Recently, Liu presented a new hydraulic walking sinking stage, which provides centralized control, automatic control and security control on the movement of sinking stage [10]. Based on the conditions of Da Hai Ze Coal Mine, mechanical behaviors of the hydraulic walking sinking stage were also checked by using FEM method [11].

On the basis of the above studies, it is a suitable way to develop a hydraulic self-walking sinking platform for solving the hanging problem in deep shaft construction. However, this technology is still far from being application ready and needs to continue improvement. In this paper, series of numerical and physical model tests were conducted to clarify the mechanical properties of this new hydraulic self-walking sinking platform under various sinking conditions. These results can provide a support for application of the HWSP in future.

MODEL DESIGN

Figure 1 shows a 3-Dimensional model and a numerical model of the studied hydraulic self-walking sinking platform in this paper. The prototype of HWSP is steel structure with 16.0 m high and 7.7 m in diameter, is composed of four layers, each layer of 4.0 m height in general. Designations of each layer from top to bottom are the upper layer, the reinforcing layer, the walking layer and the lower layer. Four vertical hydraulic cylinders (be defined as the walking cylinder) are equipped between the upper layer and the walking layer that use to adjust space between the two layers. Six column are used to connect the upper layer and the lower layer by passing through the walking layer. There are eight horizontal hydraulic cylinders distributed uniformly on the upper layer and the walking layer in respectively. Each horizontal hydraulic cylinder is connected with a hanging corbel and drive a corbel stretch out and insert into a reserved grooves that the sinking platform could be hanged on the shaft wall without suspension ropes.



(a) Prototype (b) Numerical model by SAP2000

Figure 1: 3-Dimensional model of the HWSP

According to the comprehensive conditions of HWSP (such as material, walking process, working condition, etc.) and the limitations of our laboratory, a scale ratio of 1:10 was selected to model the HWSP. The major scale relations are listed in Table 1. The steel type of all the members was steel Q235 and the connections were similar to that of the prototype according to the scale relations. Typical section of members are shown in Fig 2.

Table 1: Scale relations between model and prototype

Type	Physical variable	Dimension	Model coefficient
Geometrical property	Length (L)	L	$C_L = 1/10$
	Linear displacement (χ)	L	$C_\chi = C_L = 1/10$
	Sectional area (A)	L^2	$C_A = C_L^2 = 1/10^2$
	Inertia moment (I)	L^4	$C_I = C_L^4 = 1/10^4$
Materials	Elastic modulus (E)	FL^{-2}	$C_E = 1$
	Stress (σ)	FL^{-2}	$C_\sigma = C_E = 1$
	Strain (ε)	FL^{-2}	$C_\varepsilon = C_E = 1$
Load	Force (P)	F	$C_p = C_L^2 = 1/10^2$
	Liner load (q)	FL^{-1}	$C_q = C_L = 1/10$

Unit: mm

(a) Beam I63C (b) Beam I56C (c) Beam I36B

(d) Ring beam [36B (e) Column (f) Corbel

Figure 2: Typical section of members in HWSP model

MODEL TESTS ON THE NEW HWSP

Working conditions of HWSP

According to a shaft sinking process, there are two typical operating conditions of sinking platform: the fixed condition and the moving condition (moving up or down). In the fixed condition, the sinking platform is at more unfavorable condition when the loading grab is working due to the dynamic loading effect. Correspondingly, for the moving condition, it is at more dangerous condition when only one, either corbels on the upper layer or on the walking layer are works. Therefore, in this paper, three test cases were considered: the fixed case, the case of only corbels on the upper layer are hanged and the case of only corbels on the walking layer are hanged. In which the latter two cases are referred as the moving case collectively. Detail loads of working conditions in sinking platform model tests are shown in Table 2.

Table 2: Working loads applied on the HWSP model

Loads	The fixed case	The moving case
Loading grab Q_L	2×80.8* kN	2×80.8 kN
Template Q_T	294.4 kN	--
Drainage pump Q_D	30.7 kN	30.7 kN
Water tank Q_W	95.0 kN	95.0 kN
Concrete Q_C	20.0 kN	--
Hydraulic station Q_H	17.4 kN	17.4 kN
Workers and etc. Q_P	19.2 kN	19.2 kN

*The weight is multiplied by 1.2 when considering the dynamic effect of grab loading.

As shown in Table 2 and Figure 3, loads of loading grab, concrete and drainage pump are applied on the lower layer of sinking platform model. Loads of water tank and hydraulic station are applied on the walking layer. Loads of workers and etc. are divided uniformly and then applied on each layer of sinking platform model. It shows that the main working loads act upon the walking layer and the lower layer, and it should be clear that some load patterns are actually simplified during model tests. Such as load of grab Q_L is divided into eight point loads and applied on the corresponding beams of the lower layer. Through a comparative analysis by numerical simulation, these simplifications could be acceptable.

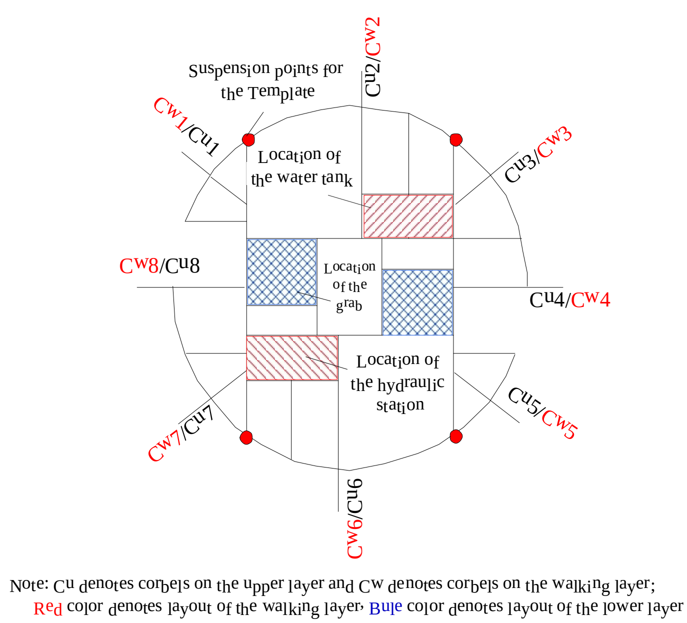
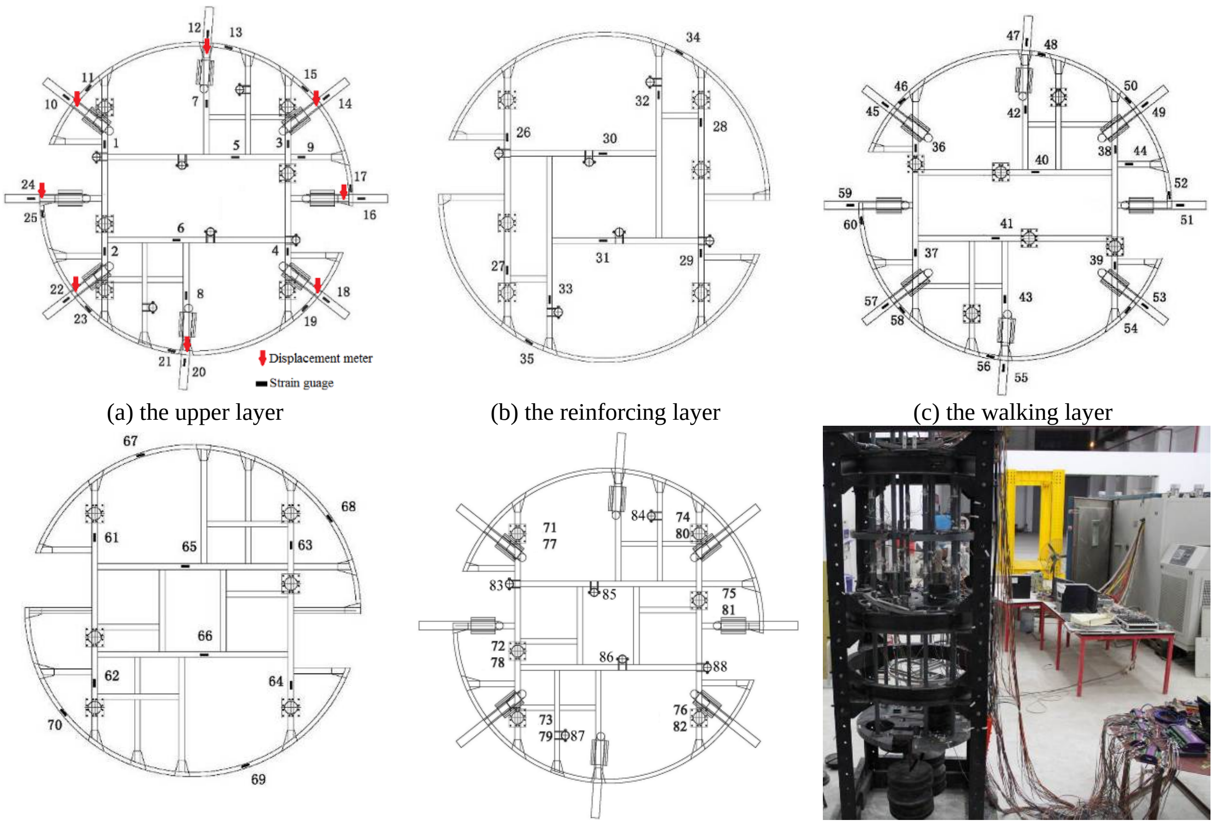


Figure 3: Location of equipment on the HWSP

Measurement and data acquisition

The strain gauge arrangement of the HWSP model is shown in Figure 4. The arrangement was based on the results from numerical simulation tests by SAP2000 program. Some 88 electric strain gauges were pasted on the middle section of the members of HWSP model to measure the strain. A meter was fixed at each support corbel to record the vertical displacement. A DT80G was used as the data acquisition equipment.



(a) the upper layer (b) the reinforcing layer (c) the walking layer

(d) the lower layer (e) columns (f) photo of HWSP model

Figure 4: Layout of strain gauges and displacement meters

Model tests arrangement

The model tests were carried out in the State Key Laboratory for Geomechanics and Deep Underground Engineering of the China University of Mining and Technology. The tested HWSP model and loading devices are shown in Figure 4(f). First, we fixed the HWSP model into the adjusted test platform, rectified the height of the walking cylinder, supported corbels and connected the test instruments. Then, working loads were applied to the HWSP model in form of weights step by step. As we know, if plastic deformation or damage occurs in steel construction, the internal stress state of members will not be able to return to its initial state. On the other side, numerical simulation by using SAP2000 program were also carried out, thus verify and replenish with the experimental model tests. The results from these tests could reflect the reality.

RESULTS ANALYSIS

Mechanical behavior of the HWSP model

The hydraulic self-walking sinking platform was first modeled by SAP2000 program to investigate the mechanical behaviors of HWSP under different test conditions. For instance, Figure 5 to Figure 7 show the max. stress ratio of members on the walking layer, the lower layer and the columns under the fixed case, respectively.

As shown in Figure 5 to 7 and Table 3, it can be seen that the dynamic loads of grab loading has a significant effect on the whole behavior of the HWSP model and thus the fixed case is the most adverse condition. Furthermore, the maximum stress ratios of all members on each layer are lower than 1.0, and the results from the physical model tests have good coherence to numerical data. Hence, it could reasonably conclude that the structural stability of the hydraulic self-walking sinking platform can meet the demands of design. It is also important to note that the maximum stress ratio of the corbels is 0.976, which is close to its limit. It would be an important aspect for the future application of the HWSP.

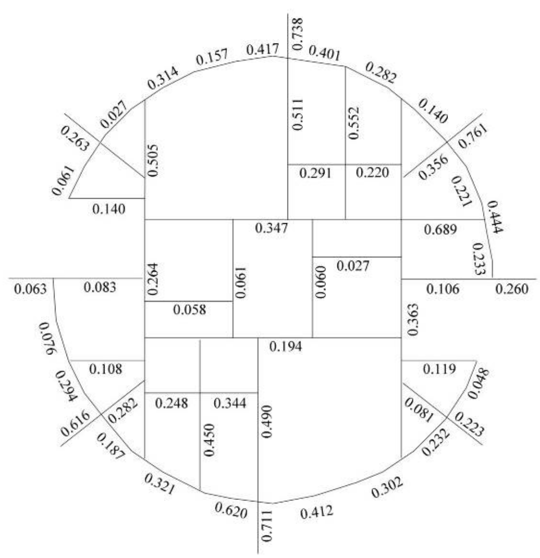


Figure 5: The maximum stress ratios on the walking layer of HWSP model under the fixed case by SAP2000

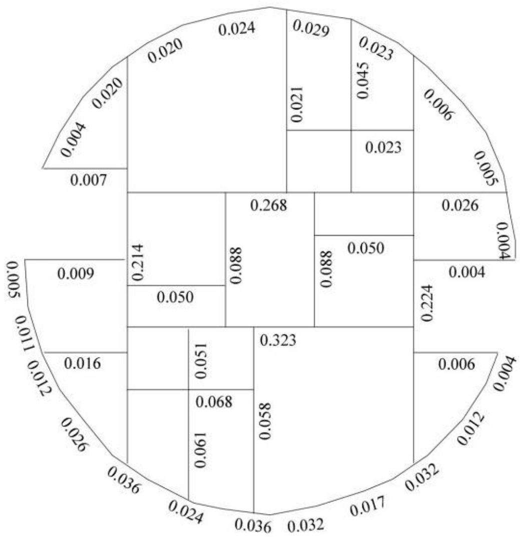


Figure 6: The maximum stress ratios on the lower layer of HWSP model under the fixed case by SAP2000

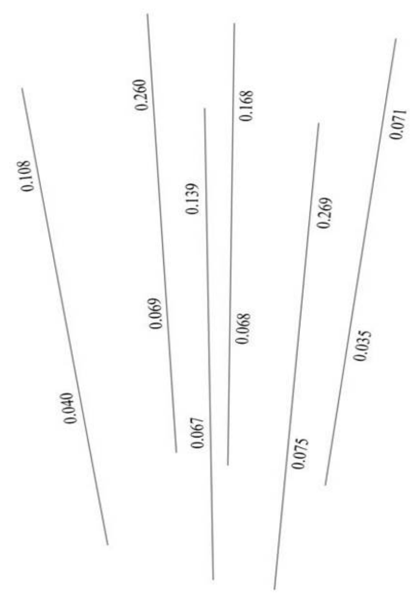


Figure 7: The maximum stress ratios on columns of the HWSP model under the fixed case by SAP2000

The maximum stress ratios of each beam and column under different working cases are summarized in Table 3.

Table 3: Working conditions of the HWSP in model tests

Layer	Member	The fixed case	The moving case*	
			Upper	Walking
The upper layer	Main beam	0.306	*0.347*	0.187
	Secondary beam	0.397	*0.656*	0.456
	Ring beam	0.602	*0.890*	0.254
	Corbel	0.527	***0.926***	0.050
The reinforcing layer	Main beam	0.592	0.626	0.528
	Secondary beam	0.038	0.083	0.076
	Ring beam	0.049	0.129	0.096
The walking layer	Main beam	0.363	0.093	*0.584*
	Secondary beam	0.552	0.352	*0.750*
	Ring beam	0.677	0.133	*0.701*
	Corbel	0.761	0.029	***0.976***
The lower layer	Main beam	0.323	0.251	0.248
	Secondary beam	0.068	0.057	0.055
	Ring beam	0.036	0.036	0.035
--	Column	0.260	0.275	0.041
--	Walking cylinder	0.493	0.560	0.403

*Upper and walking denote the case of only corbels on the upper layer are hanged or corbels on the walking layer are hanged, respectively.

Displacement and support reliability of the HWSP model

Figure 9 and Figure 10 show forces of the corbels under the fixed case and the moving case from numerical model tests and physical model tests in the lab. It can be seen that errors of the sinking platform manufacture and the reserved grooves construction may cause an imbalance bearing among the six hanging corbels. In this case, the corbel which suffers more unbalanced loads will be the first place to be destroyed under long-term load that affect the security and reliability of the HWSP. This will be significant for practical application. Therefore, by using the structural stability model of the HWSP, series of additional tests were carried on to verify the effect of uneven bearing of the corbels.

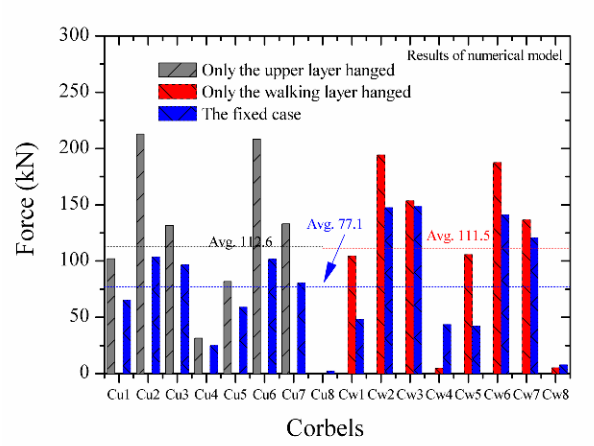


Figure 8: Forces of the Corbels on HWSP model by SAP2000

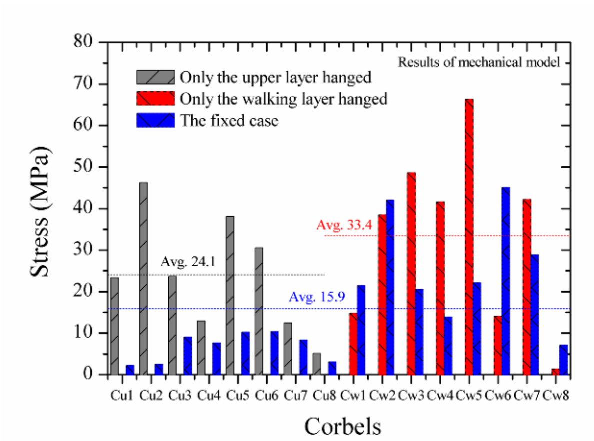


Figure 9: Forces of the Corbels of the HWSP in the lab

As we know, three points determine a plane and at least, there are three of the corbels are in action to hanging the platform. Based on this idea, some of the corbels are randomly selected and be invalidated and then of which the displacement are measured. The average displacement of the unsupported corbel in each test case are listed in Table 4.

Table 4: Average displacement of the unsupported corbels

Number of enable corbels	Average displacement of unsupported corbels /mm			
	Cu2-Cu5-Cu8*	Cu2-Cu5-Cu7	Cw3-Cw5-Cw8	Cw3-Cw5-Cw7
3	68.5	36.3	101.5	47.3
4	54.2	34.5	83.1	41.9
5	43.7	32.5	62.5	35.5
6	35.0	23.5	49.8	31.2
7	28.6	19.8	46.4	23.8

*shows the basic three supported corbel in each test case.

For instance, Figure 10 shows the average displacements of the invalidated corbels of the HWSP under two test cases. It shows that there are at least five enable corbels on each layer when positional tolerance among each corbels or grooves are less than 50 mm, and in this case, it has a reliable assurance for the hanging security of the HWSP model based on both the numerical and physical model test results.

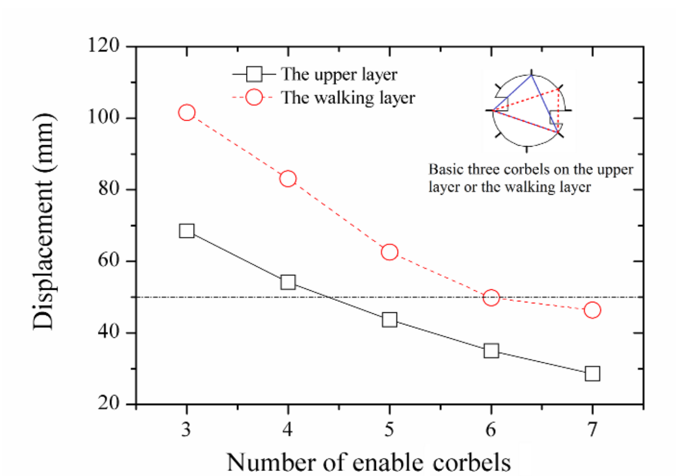


Figure 10: Displacements of the invalidated corbels

CONCLUSION AND DISCUSSION

The paper discusses technological innovation ways of hanging mode of a sinking platform, and clarifies the mechanical behaviors of a new hydraulic self-walking sinking platform by using numerical and physical model test method. The test results show that it has good performance and application possibility for the future deep shaft construction. However, it also shows its shortcomings, such as needs to reserve the grooves on the shaft wall and the mobile reliability largely depends on the quality of construction. To solve these issues, further works are needed

ACKNOWLEDGEMENTS

This work was support by the National High Technology Research and Development Program of China (863 Program) (Grant No. 2012AA06A402), the National Science Foundation for Post-doctoral Scientists of China (Grant No. 2014M551701) and the Fundamental Research Funds for the Central Universities (Grant No2013QNB22).

REFERENCES

[1] Yi X.B., Xu S.L., Zou G.L., Sinking equipment matching and application in large-diameter and deep-frozen shaft, Jiangxi Coal Science and Technology, (2), 100, (2014).

[2] Gao Y.Q,, Ultra large diameter vertical shaft drilling a well working platform design and construction, Shandong Coal Science and Technology, (5), 25, (2010).

[3] Li J.C., Design on three sinking stage of large diameter mine shaft, Mine Construction Technology, 35(3), 54, (2014).

[4] Wang Y.D., Cao G.H., Liu Z., Mao G.F., Study on optimization of sinking platform structure design for ultra deep mine shaft construction, Coal Science and Technology, 41(2), 78, (2013).

[5] Shi T.S., Guo J.P., Wang J.P., Modification of sinking equipment hanging technology for deep shaft sinking, Coal Science and Technology, (6), 13, (1992).

[6] Liu Y.S., Deng W.Q., Yang T.C., Hydraulic walking sinking platform WMP type and its technical economical reasonableness, Coal Mine Machinery, (2), 24, (1980).

[7] Zuo S., Li A.M., Research and design of moving hydraulic metallic template, Coal Mine Machinery, 32(55), 20, (2011).

[8] Wang B., Liu J.K., Xu D.Q., Li X.F., Physical simulation test on mechanical characteristics of sinking platform in deep shaft, Journal of Mining and Safety Engineering, 30(Supp.2), 283, (2013).

[9] Wang Y.F., Liu Z.Q., Li X.F., Wang B., Research on sinking platform structure and steel selection of deep and large shaft, Coal Science and Technology, 43(1), 91, (2015).

[10] Liu J., Wang Z.Q., Qiu T.D., Long Z.Y., Wang Z.L., Study on the design of a hydraulic walking sinking stage, Mine Construction Technology, 34(3), 27, (2013).

[11] Liu Z.Q., Zhao W.P., Du J.M., Structural internal force analysis and section check of moving the whole of the hydraulic hanging scaffold, 30(Supp.2), 229, (2013).