Early King Post Cutting in Top-Down Excavation Work

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This paper shows an analysis method and result for early king post cutting in top-down excavation work of Ho Chi Minh City Metro Line 1 Opera House Station. The analysis consists of modelling using finite element method (FEM) involving feedback from trial cutting monitoring reading.

1. INTRODUCTION

Opera House Station of Ho Chi Minh City Metro Line 1 is a part of Contract Package 1b (underground) that located in the city center. Due to limited space in the area, the station was designed to accommodate a stacked arrangement of underground trackway which required four levels of basement (B1F to B4F) reaching up to 30.8 m depth. Top-down excavation method was chosen to minimize retaining structure displacement and ground settlement. Temporary king posts were installed prior to excavation to serve as temporary support for permanent structure. The element of king post support system consists of temporary support beam and shear connector to transfer the load from slab and girder to king post (Figure 1). Load acting on slab and girder will be transferred to king post through temporary support beam and shear connector. When permanent structure is built (step 1-2-3 in Figure 2), king post can be cut and the load supported by it will be transferred to permanent column. To expedite subsequent finishing works, the king posts at B1F level were cut before completion of B4F columns (step 1-2-3i in Figure 2). Therefore, a structural analysis related to the cutting plan was carried out to ensure a safe construction sequence.

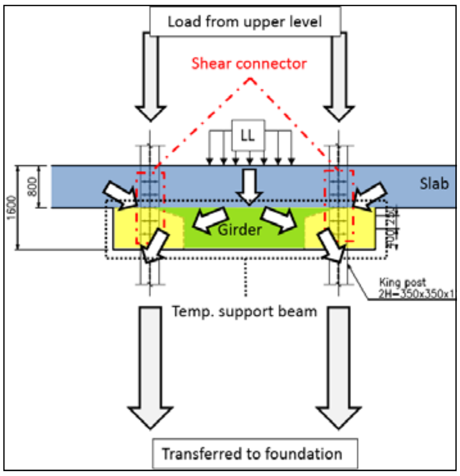

Figure 1. Element of king post connection at permanent slab

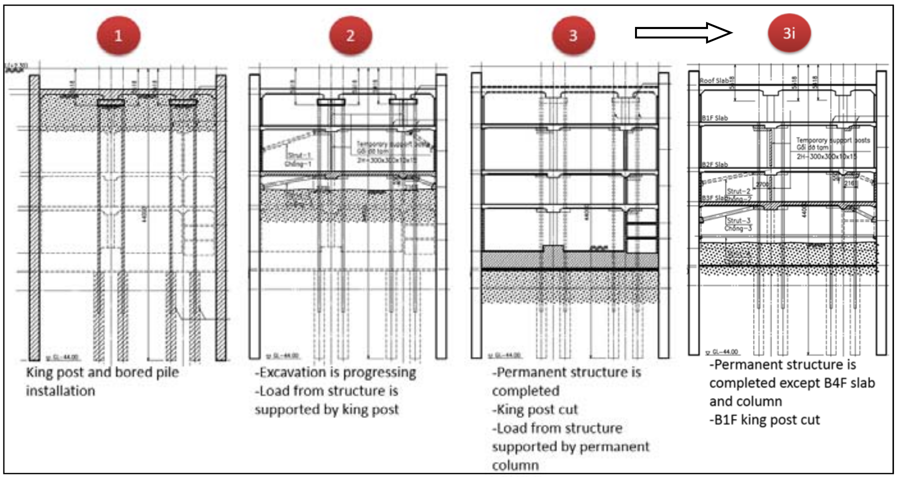

Figure 2. Construction sequence in original (1-2-3) and modified (1-2-3i) scheme

2. ANALYSIS METHOD

To check the magnitude of transferred load or additional load from roof slab due to B1F king posts cut, a FEM model of full station structure was carried out using structural analysis software STAAD Pro (Figure 3). Since it cannot model continues construction sequence, a step by step analysis was carried out. An initial temporary stage model was created first. Then, a case of omission of B1F king posts was modelled. A difference of force in the structural element (e.g. column and king post) between two cases was considered as a transferred load. Thus, a distribution of transferred load can be predicted. The predicted value was used as a reference to verify the model in the monitored trial cutting.

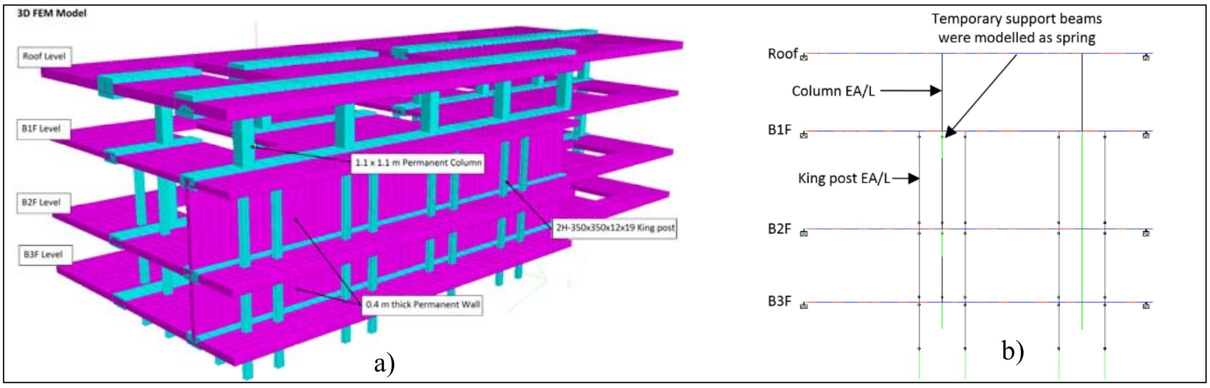

Figure 3. Opera House Station FEM model in a) rendered view and b) cross-sectional view

Keyword: finite element analysis, king post cutting, top-down construction method
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3. MONITORED TRIAL CUTTING AND LOAD TRANSFER MECHANISM

The king posts and columns were monitored by attaching strain gages on their surface to identify magnitude of load transferred to each element. The trial cutting was done three times. In the first and second trial cutting, strain gages (SG) were attached on B1F to B3F column and B1F to B4F king post. In the third trial cutting, only B1F to B2F columns and kingpost were monitored. Additional two pairs of SGs were also attached on slab to monitor temporary support beam of B1F in the third trial cutting. The typical monitoring arrangement is shown in Figure 4.

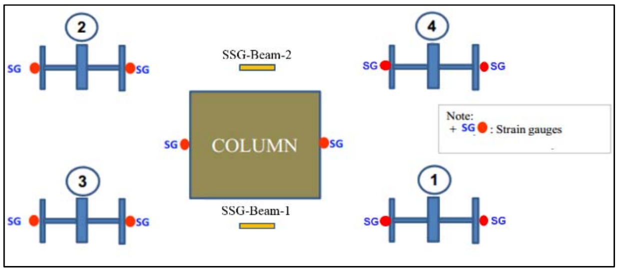

Figure 4. Plan view of typical arrangement of monitoring sensor

The first and second trial cutting revealed that only small percentage of load was transferred from B1F column to B2F column. And an ignorable fraction was reached B3F column. It was the opposite from initial assumption where the load from roof slab was expected to be transferred mainly through B2F and B3F columns and then dispersed to king post below B3F slab. The output from first trial cut monitoring was used to refine the model by applying 100% stiffness (EA/L) for B1F column and 2.5% of stiffness for B2F column. The lesser load transfer distribution to below B1F was due to the role of temporary support beam. It absorbed most of the load. Therefore, another analysis was carried out to check the structural condition of temporary support beam imposed by the additional load from roof slab.

4. ANALYSIS RESULTS

After modification of stiffness ratio for B1F and B2F columns, the predicted result showed similar trend with monitoring output (Table 1). The 250 kN different for B1F column could be justified from the absent of actual roof slab corbel weight from the model. It is noted that the actual load detected from B2F king posts showed tension (positive sign) due to removal of king posts of B1F. The released load was recorded from each B1F king post by taking strain gage value before and after cutting. The total release load (4943 kN) was close to design load calculation for the king post (5000 kN).

Table 1. Monitoring reading from trial cutting and prediction value

Monitoring Items	Location	Monitoring Points	After Cutting KP1 - B1	After Cutting KP2 - B1	After Cutting KP3 - B1	After Cutting KP4 - B1	Prediction
Axial Load (kN)	B1F	SG-KP1	2134*				
		SG-KP2	45	1306*			
		SG-KP3	-348	-434	734*		
		SG-KP4	-162	-396	-436	769*	
		SG-Col	-817	-1539	-1767	-3771	-3521
	B2F	SG-KP1	195	268	269	297	273
		SG-KP2	-51	68	38	122	-73
		SG-KP3	-63	-63	-88	84	317
		SG-KP4	-58	-41	-69	80	-105
		SG-Col	-102	-74	-141	-234	-327
Stress (N/mm^2)	B1F	SG-Beam-1 (Top)	-0.55	-0.55	-0.69	-1.18	-2.64
		SG-Beam-1 (Bottom)	-0.05	-0.03	-0.13	-0.10	1.85
		SG-Beam-2 (Top)	-0.57	-0.39	-0.58	-0.71	-2.64
		SG-Beam-2 (Bottom)	-0.17	-0.13	-0.20	-0.14	1.85

Note:
- Value in (-) means load increment (compression); (+) means load decrement (tension)
- *) indicates released load

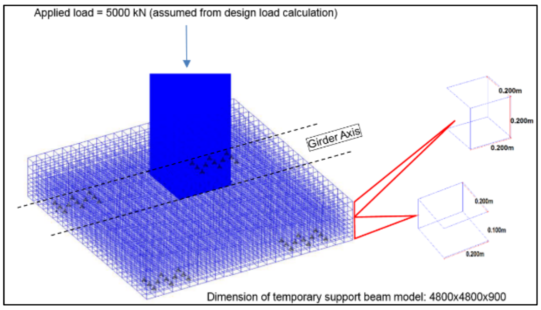

Figure 5. FEM solid model for temporary support beam

To predict the impact of absorbed load by temporary support beam, another FEM analysis with solid model was carried out as shown in Figure 5. To simulate the worst-case load, the model was subjected to 5000 kN load. The stress contour from the simulation showed that, at the location of SG on temporary support beam, maximum tensile stress generated will be 1.85 N/mm^2 which is still less than the calculated concrete tensile strength of temporary support beam (1.91 N/mm^2) (Figure 6). Meanwhile the actual stress measured by SG are less than prediction (Table 1). Hence, the temporary support beam could bear the impact of the absorbed load.

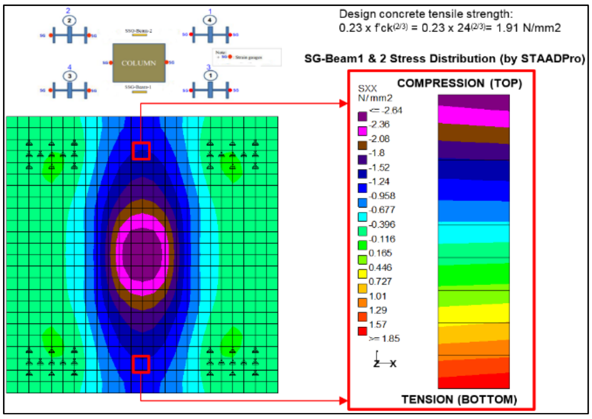

Figure 6. Stress contour from temporary support beam simulation

5. CONCLUSIONS

From the result of analysis and monitored trial cutting for early king post removal in top-down excavation work, it is revealed that prior to the cutting, no load being transferred to column even though it has been constructed. Column (at certain level) will be activated when king post at that level were cut. The role of temporary support beam is significant to retain the transferred load from cut king post due its big stiffness. Early king post cutting helps to expedite finishing works especially for deep underground structure construction. Therefore, additional margin shall be added to temporary support beam and shear connector design to account for impact from early king post cutting in the future.

REFERENCE

Shimizu-Maeda Joint Operation: Trial King Post Cutting Report in B1F Grid OC-14, Opera House Station, 2017