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New Resolution for Historic Building Conservation by Building Moving Technology

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Abstract: To contradict from the rapid development of economy and urban construction, the conservation and strengthening of historic buildings are becoming more and more important and requiring more wisdoms and new technologies. A new resolution for protecting historic buildings by building moving technology is introduced and discussed with several application projects. Firstly, three building moving methods are presented which include moving building with rolling bars, moving building with slide layer and moving building by trailer transportation. Secondly, control system and structural state monitoring for building moving are described. Lastly some completed historic building moving projects are introduced for demonstrations of this technology application.

Keywords: historic buildings; conservation; structural strengthening; building moving, moving control system; moving device; real-time monitoring.

Introduction

Building moving is a kind of procedure to relocate the position or direction of existing buildings while to keep the integrity and functionality of those buildings without deterioration.

The building moving project was firstly performed at the end of 19th century in New Zealand (Lamar 1999), and since then there were a great number of successful applications and projects for the purposes of conservation for existing buildings (Gini 2000). Even though building moving technology was applied in mainland of China after 1980s, the particular technology for moving buildings has been rapidly developed, i.e. to the end of 2009, there are more than one hundred successful building moving projects with abundant experiences in China (Tang 2006).

For historic building, building moving technology is proved to be a new resolution to protect and conserve its original state with function and safety. The main advantages of conserving historic buildings by using moving engineering are generally summarized as following.

1) Easier conservation and maintain the historic building with its original layout, facade as well as architecture details, the upper floors of the building will easily maintain its service function during the moving schedule.

2) Lower carbon and friendlier environment, comparing with tradition construction, building moving will create more reuse resources, less constructional rubbish, and lower construction noise.

3) Higher economic profit and society effect, the budget of moving projects is usually 30%~70% of the similar new construction project, the construction duration is almost 1/4~1/3 of traditional project, easy and efficient procedure for anticipating of the related residential and enterprise.

The following technologies with application of conservation and maintain the historic building are investigated and discussed in this paper, as illustrated as following.

1) Various building moving methods.

2) Underpinning method of RC columns.

3) Moving control system and moving power equipment.

4) Monitoring technology of the building moving, and
5) Relocating moved building with combined isolation system.

Building Moving Technology

The building moving procedure includes three categories as follows.

1) Monolithic moving the building along longitudinal, transverse or an angle directions to a new location,
2) Rotating building or moving it along a curve path to a new location, and
3) Jacking, descending or rowing the building to adjust position, etc.

The building moving methods for monolithic moving are usually described as, moving building with rolling bars, moving building with slide layer and building moving by trailer transportation.

Application of Building Moving with Rolling Bars

The rolling bars are usually made of steel bars or concrete in filled tube, which is distributed in-between the underpinning and lower track system. The method is suitable for buildings with small span bays and easy to be transferred to a rigid underpinning system, especially for those buildings which will be moved along straight level tracks to the new positions. Fig.1 and Fig.2 shows two typical historic building moving with rolling bars. Jinlun Guild Hall (Fig. 1) was constructed at Qing Dynasty (1723), and moved 102.5m. Ciyuan Temple Buildings (Fig. 2) were constructed 1300 years ago, and moved 1256m.

Figure 1: Jinlun Guild Hall

Figure 2: Ciyuan Temple

Application of Building Moving with Slide Layer

For the slide layer, there are two kinds of bracket for foot support, which are rigid slide foot bracket and floating slide foot bracket. The method is suitable for buildings with different span bays and having various vertical loading for each member at first floor, especially for those buildings which will be moved along a slipe tracks to higher or lower level.

Shanghai Concert Hall was built in 1930 with floor area of 2600 m^2, height of 21m and weight of 4500 tons. The building has typical western style façade and valuable music hall, which was enrolled into historic building in 1989. For the purpose of conserving this building and enhancing its function, the building was moved at a distance of 66.46m, and raised level of 3.38m, as shown in Fig. 3.

No. 4 Building of Minli High School of Shanghai was constructed in 1920s. It is a 1812 m^2 brick-wood building, and has been ranked in Shanghai famous historic building with Conservation Rank 3. The building was moved 70m with floating slide foot bracket. The complication and difficulty of monolithic moving the very weak and sensitive structure were surely great challenge to engineers to perform this project. Some key technologies were applied, which included the method of monolithic moving line, lifting project, underpinning system, foundation and lower track, moving device, moving power, pushing technology, connection measures between the new and the original foundation, etc, which had the advantage of easy control, time saving and low cost. The building moved at a distance of 57.66m, and raised level of 0.40m, as shown in Fig. 4.

Figure 3: Shanghai Concert Hall

Figure 4: No. 3 Minli High School Building of Shanghai

Application of Building Moving by Trailer Transportation

Trailer transportation is suitable for long distance building moving, and the moved building shall have relatively small size and light weight. Most of timber structures and masonry buildings in abroad projects were moved by special trailers or ships to a relatively long distance. In China, there is only one project performed and documented. A small historic villa was safety transported by special trailer to 30km away, which is illustrated in Fig. 5.

Figure 5: A small historic villa moving by trailer transportation

Underpinning Technology of RC column

With experiment on groups of RC frame column wrapped underpinning joints, the three factors influence to the underpinning RC column were summed as the ratio of span to height of underpinned beam, the ratio of underpinned beam stirrup steel bar and the ratio of underpinned beam longitudinal steel bar, as shown in Fig. 6. Based on the experimental results, the underpinned joint stress mechanism and failure form was studied, and the ratio of underpinned beam span to height was one of the key factors to the joint failure styles and the failure mechanism. The shear resistance V of RC unpinning joint is estimated as equation (1) (Tang 2006, Liu 2007).

Figure 6: Experiment on RC wrapped underpinning joints

$$V=\min\{\frac{1.75}{\lambda+1}f_t bh_0+0.67k(\lambda-0.5)\rho_{sv}f_{yv}bh,\ V=K_i f_c A\} \quad (1)$$

in which, $\rho_{sv}=\frac{A_{sv}}{bs}$ is stirrup reinforcement ratio,

λ—shear moment ratio， $3<\lambda<1.5$,

K—adjust parameter, $0.5<K<1.0$,

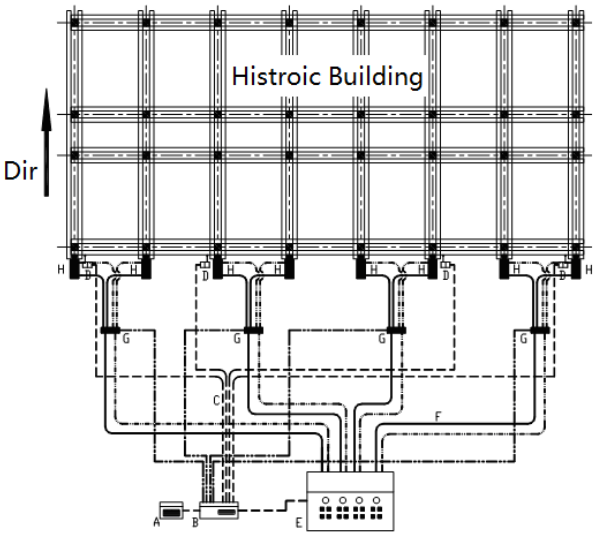
f_{yv} —strength of reinforce bars

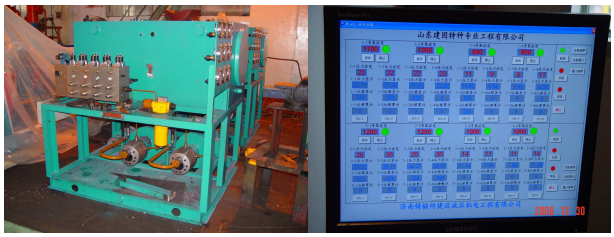
The tests and analysis results of underpinning of RC columns were applied in moving projects of Shanghai Concert Hall and No. 4 Building of Minli High School of Shanghai, etc.

Building Moving Control System

PLC hydraulic control system is composited by hydraulic devices (pumping and jacks), monitoring sensors and computer control system, as shown in Fig. 7.

PLC hydraulic control system has the characteristics of easy operation, friendly interface, online control, safety and reliability and multiple functions, etc.





Control Devices

A—control panel, B—electronic interface
C—signal cables，D—displacement sensors
E—hydraulic pumping system
F—pipe line and hose
G—valves and hydraulic sensors
H—Jacks

Figure 7: Illustration of building moving control system

Monitoring Technology of Building Moving

There are many issues related to the safety of building moving, which are listed as following (Li 2009).

1) The structural safety condition and margin of building.
2) The measurement and details of structural appraising and strengthening.
3) The departure method and interface in between the building and foundation.
4) The settlement of foundation and lower-track structural system.
5) The strength, stiffness and stability of underpinning system.
6) The reliability of moving control system and power supplier, and
7) Unexpected action, such as earthquakes, winds, and other actions.

Hence reliable monitoring system and feasible methods are very important to the safety of building under moving. After analysis of the safety issues of building on each phase of moving procedure, the related monitoring item and key point are summarized as table 1.

Table 1: Monitoring Items on each phase of moving buildings

Each phase of building moving	*Monitoring Items*
Original position	Structural apprising and safety assessment, settlement survey, structural state of the building, levelling of sub-track lower track system, dynamic properties
Moving procedure	Structural state of the building, settlement survey, monitoring on sensitive strains and critical cracks , dynamic behaviour tests
New Position	Structural state of the building, settlement survey, dynamic properties

The most difficult step for monitoring a moving building is to master and merge the large amount of recorded data and phenomena in time, to assess the safety conditions of moving buildings and related structures, and to give reasonable judgments on the next moving procedure.

Application of Relocating Moving Building by Combined Isolation system (Dong 2008, Chen 2009)

The traditional way for moving building to new location is to fix its structural members to new foundation, and demolish the lower tracks. However, for moving historic buildings, it's difficult to demolish the lower tracks from the weak and sensible structures. Moreover, the structural integrity and seismic capacity of historic buildings are insufficient, and need to be strengthened. The authors study and try to relocate the moving building to new position with combined isolation system which includes lead rubber bearings and slide bearings. Firstly the numerical models of moving building with combined bearing, as well as the dynamic properties and dynamic responses of buildings with combined base isolation were analyzed and investigated. Then static and dynamic experiments on structure with combined base isolators were performed to verify and approval the isolation effective and mechanism. Finally the combined isolation system was applied to several moving projects of conservation of historic buildings.

Qingshuiwan Historic Building was built in 1925 with floor area of 1,200m^2, height of 9.5m and weight of 2,000 tons. The building was combined with typical western style façade and Chinese internal hall. The building was moved at a distance of 70.00m, rotated 35°and raised level of 1.80m. The new site will be a two storey RC basement. A combined base isolation system was designed and distributed in between the underpinning system and new constructed strong basement, and the underpinning system is considered to be a rigid transfer base of up-structure, as shown in Fig. 8 and Table 2.

Figure 8: a) Qingshuiwan Historic Building

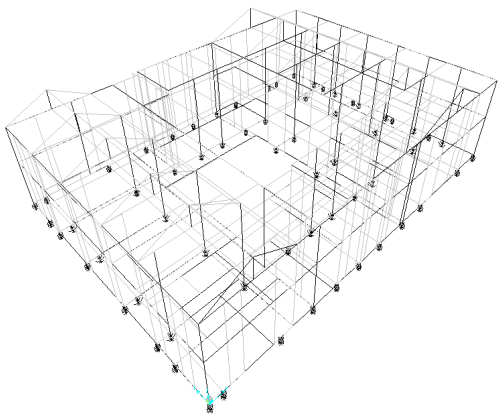


Figure 8: b) Numerical model

Table 2: Isolators bearing specification

Brand and Type of Bearing	*Diameter（mm）*	*Amount*	*Remark*
LRB300	300	36	Lead rubber bearing
AS300	300	28	Slider bearing

The author optimized the location of moving support bracket and rubber bearings according to the safety requirement of the historic building during moving and after relocation. The combined bearings were designed to support the up structural mass, to withstand wind loading, earthquake action and overturning moment, etc. The basic natural frequency of the structure was about 5Hz, while the dominate frequency of site soil was 1Hz, as shown in table 3. The moving building was relocated with combined base isolation system, that means the natural frequency of the structure is much lower than the dominate frequency of the site soil with higher damping, which satisfied seismic performance. It's proved that the drifts of the bearing under earthquake be within the elastic range under frequently occurred earthquakes, and less than 150mm under seldom occurred earthquakes.

Table 3: Dynamic properties of relocated historic building

Relocating Style / Mode Order	*Fixed Base*		*Isolated Base*		
	Period(s)	*Pati. Mass*	*Period(s) Frequently Occurred 7*	*Period(s) Seldom Occurred 7*	*Pati. Mass*
1st	0.1786	UY:0.26	1.2136	1.6687	UY: 0.86 RZ:0.44
2nd	0.1639	UX:0.33	1.1974	1.6461	UX:0.93 RZ:0.41
3rd	0.1459	RZ:0.78	1.0406	1.4303	RZ:0.15

Several historic buildings in Shandong Province were also relocated with combined isolation system after moving (as shown in Fig. 9), and be proved as following.

1)The advantage of relocating the moving building with combined base isolation system are to take advantage of the rigid underpinning system and strong basement on new site, i.e. it is easier to achieve the double win of structural safety and building function conservation,

2) With combined base isolation system, the natural period of the moving building is expanded and much longer than the dominate period of the site soil. Hence the earthquake action of structure will tremendous reduced with longer period and higher damping,

3) The shear force and drift of each storey will be reduced, while the overturning moment will also be reduced, and

4) The up-structure is easier to keep in elastic range under server earthquakes, that means the construction details and seismic countermeasure of the building will be simplified during retrofitting, and be proved helpful for protecting historic buildings.

Summary

A new resolution for protecting historic buildings by building moving technology is introduced and discussed with several application projects. Firstly, three building moving methods are presented which include moving building with rolling bars, moving building with slide layer and moving building by trailer transportation. Secondly, control system and structural state monitoring for building moving are described. Lastly some completed historic building moving projects are introduced for demonstrations of this technology application.

Figure 9: a Ancient Bank of Weiliu Road of Jinan

Figure 9: b Hongji Clinic Hall of Jinan

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