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A New Level of Integration of Design and Construction Solutions

设计与施工解决方案一体化的新水平

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Abstract

The Dazongli mixed use development in the center of Shanghai city encounters an array of challenges which result from existing buildings on site and city metro tunnels crossing the site as well as design changes during the course of the project. Innovative structural engineering approaches have been instigated in this project to fulfill building performance criteria, architectural and functional requirements as well as phased construction and methods. An integrated approach has been adopted in the building structural design and construction process which interacts and impacts each other, to develop optimal solutions with efficiency, time and cost in mind. These skills and experiences are applicable to any similar mixed use development in China.

Keywords: Integration, Constraints, Innovation, Design Solutions, Construction Methods

摘要

位于上海城市中心的大中里综合体开发项目遇到诸多来自场地上原有建筑，城市地铁隧道，以及设计变更的挑战。创新结构工程方法在这个项目中得以实施，以满足建筑的性能标准，建筑设计和功能要求，以及分期建设和施工方法。在建筑结构设计和施工过程中采用一体化的方法充分融合两者的相互作用和影响，从而制定具有效率，考虑时间和成本的最佳解决方案。这些技能和经验适用于中国其他类似的城市综合体开发项目。

关键词: 一体化， 限制， 创新，结构设计方案， 施工方法

The Project

The project is located at Nanjing West Road, Shanghai with a site area of 62,870 m^2 (approx. 430m north to south x 190m east to west). This large scale mixed use development comprises two tall office towers T1, T2 of 170m & 250m in height; three hotel towers T3, T5 & T6 of 71m, 71m & 76m in height; a four-story 22m tall podium as a large scale retail mall, and a four-story 22m deep basement. The total GFA of this project is 467,000 m^2. Figure 1 shows the image of the project.

The city metro line 13 adjoins the project site to the west along Shimenyi Road. The Nanjing West Road metro station is planned to be designed and constructed

Figure 1. Image of the project (Source: The Project Client)
图1. 项目的效果图 (出自: 项目业主)

项目概况

大中里综合发展项目位于上海南京西路上，场地面积为62,870平方米 (南北430米，东西长约190米)。这个大型城市综合体开发项目的规模包括两座高度分别为170米和250米的办公塔楼T1，T2; 三座高度各为71米、71米和76米的酒店塔楼T3，T5和T6，一个四层22米高的商场裙楼及22米深的四层地库; 总建筑面积为467,000平方米，项目的效果图见图1。

城市地铁13号线毗邻本项目场地的西侧红线，在石门一路旁边。规划中的南京西路地铁站将与本项目同期建设。现有的地铁2号线从项目场地的北面穿过。一座规划中的23米高的演讲厅建筑将建于2号地铁线上。本项目开始于2003年，将于2016年完工。图2示出总体规划图。

发展限制条件

地铁规定

城市地铁方面对本项目距离地下车站及隧道外侧的50米安全保护区范围内的施工建造的条件要求如下:

- 对隧道管的竖向绝对沉降 ≤ 20毫米
- 对隧道管产生的额外压力 ≤ 20千帕

at the same time as this project progresses. The existing metro line 2 runs through the project site on the west. A 23m tall auditorium building is planned to be built on top of the metro line 2. The project commenced in 2003 and will complete in 2016. Figure 2 presents the master layout of the development.

Development Constraints

Metro Criteria

The city metro bureau has set out stringent criteria for the construction of this development within 50m distance from the metro tunnel including:

- Vertical settlement induced by construction work to the metro tunnel shall not exceed 20mm;
- Additional pressure induced to the metro tunnel shall not exceed 20kPa;
- Relative bending movement caused to metro tunnel shall not exceed 1:2500; and
- Vibration peak velocity caused by construction related work shall not exceed 25mm/s.

The footprint of the two office towers T1 and T2 and associated basement area fall within the range of 50m to the metro tunnel, the designs for the two towers and the basement area therefore shall fulfill the above-stated criteria and attain the metro bureau's approval prior to commencement of construction.

Historical Building Relocation

An existing building, namely Minli Middle School (originally named Qiu's Residence) a classified Category III historical building constructed in 1920 is situated inside the site. It is a three-story partially four-story brickwork and timber building of Baroque architecture, as shown in Figure 3a.

This building is required to be retained on site but relocated 57m southeast as shown in Figure 3b, close to the western boundary so to give way for the new development. This building will be transformed into a boutique retail and club house of the development. Its existing façade and architecture are to be best preserved to its original look and repaired to its internal modern functional use.

Road Diversion

To facilitate the construction of the new metro station, the existing main road on the south, namely Shimenyi Road, is to be diverted. A band of open space in-between the hotel and office blocks within the project site is identified to be used as a temporary road as shown in Figure 4a. This decision was carefully assessed and had least overall impact to the project, however has caused significant impact to the development program and design. The provision of the temporary road inevitably cuts the site into two parts. The respective impacts are outlined as follows:

- Replan the two separate sites including logistics, accesses and construction activities;
- Consider the overall development program in conjunction with the metro station construction so to cater for the station construction as well as the adjoining basement construction, and the delay of the construction of basement area below the temporary road.

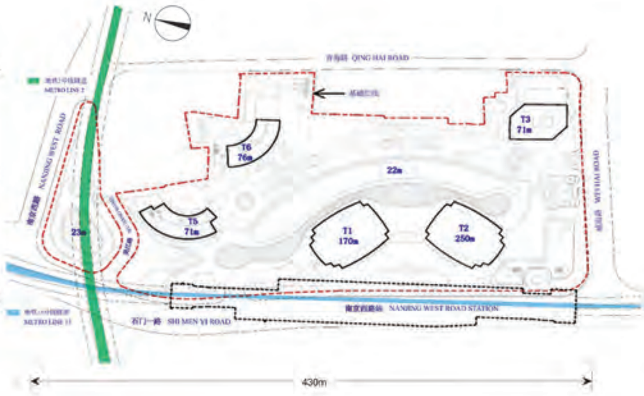

Figure 2. Master layout (Source: The Project Client)
图2. 总体规划图（出自：项目业主）

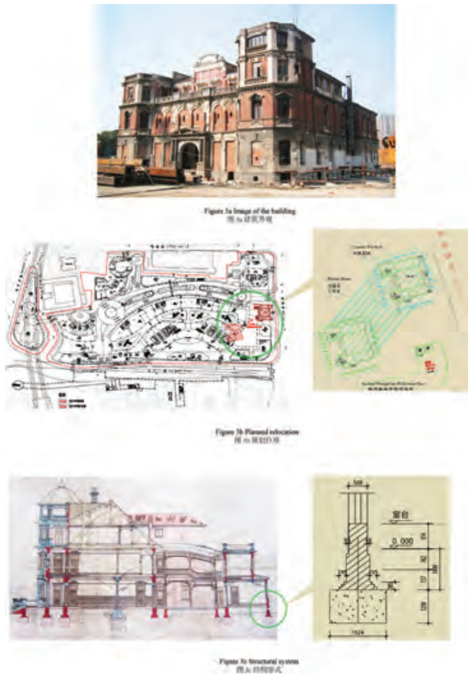

Figure 3. Minli school (Source: The project Client)
图3. 民立中学（出自：项目业主）

Figure 4. Construction plan (Source: The Project Client)
图4. 施工计划图（出自：项目业主）

- Design the basement structure to suit specific construction method for the area where the temporary road occupies once the new metro station is completed and Shimenyi Road is back for normal use.

The Structures and Technical Measures

In accordance with the prevailing Chinese codes of practice, the seismic fortification intensity is 7.0 with a design peak acceleration of ground motion at 0.10g, The site is classified as Category IV. The basic wind pressure in a 50-year and 100-year recurrence period is $0.55kN/m^2$ and $0.6kN/m^2$, respectively.

Minli School Relocation

The school structure, as shown in Figure 3c, was formed of reinforced concrete (rc) column and beam frame system at the central lobby area and two-way brickwork load bearing wall system surrounding the lobby area, i.e. for the towers at both sides and the front and rear of the lobby area. Timber floors and timber roof trusses were used apart from rc floors used for the south balconies at Levels 2 & 3 and tower roof at Level 4. Brickwork wall footings were adopted for the structural load bearing brickwork walls above and supported on lean concrete plinth of 762-1219mm in thickness and 1067-1524mm in width. Reinforced concrete pad footings of 1829 x 1829mm in size supported the rc columns at the central lobby area, and were subsequently supported on a group of 1.828m long timber piles.

The client appointed historical building specialist and contractor were on board at the early stage of the project were responsible for the design and construction of the building relocation. A seven-month period of preparation works including building conditional survey, assessment of the existing building, and structure strengthening works was undertaken. Inclined straight line hydraulic sliding movement solution was chosen after comprehensive study and analysis of feasible options by the project team mainly involving the client, the project architect, the specialist consultant, contractor, and AECOM team. The key measures of the building relocation were applied as follows:

- Strengthen the existing building, build a rc raft plate underneath the building to support the building and act as the top supporting transfer plate with built-in beams;
- Build bottom beams on ground on the designed straight line route with stainless steel top surface as sliding track;
- Install hydraulic sliding device in between the top and bottom supporting beams;
- Build new piled foundation and load transfer pile raft on top at the new location
- Cut the building superstructure off its original foundation after all the structural strengthening works, move the building along the bottom beam track onto the new pile raft at the new location by hydraulic push and pull system via PLC control and monitoring system;
- Permanently connect the building to the supports on the new pile raft with isolator installed so to mitigate seismic vibration impact to the old building;
- Top down construction was decided for the basement under the building, which is to be executed to the project program at a later stage.

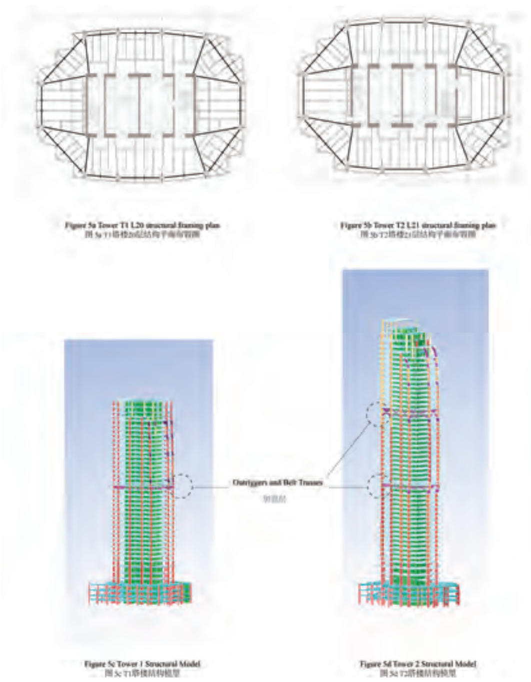

Figure 5. Tower structural system (Source: AECOM)
图5. 塔楼结构系统（出自：AECOM）

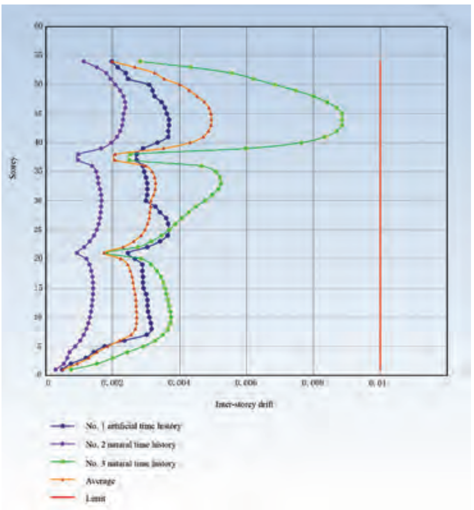

Figure 6, Tower T2 inter-story drift under severe earthquake elastic-plastic time-history analysis (Source: AECOM)
图6. T2塔楼罕遇地震作用下弹塑性时程分析层间位移角

- 对隧道管产生的相对弯曲 ≤ 1:2500
- 工程施工作业产生的振动对隧道引起的峰值速度 ≤ 25毫米/秒

两个办公塔楼T1和T2以及相关地库区域已落入上述的地铁隧道50米的安全保护区范围内，两个塔楼及地库的设计必须满足上述技术限制条件并且在施工开工前获得地铁部门的设计审查批准。

历史建筑移位

在项目的场地内矗立着一幢建于1920年的历史建筑，民立中学(原名邱氏住宅)。民立中学属于第三类保护建筑，为三层(局部四层)砖木结构，其建筑风格为巴洛克式(见图3a)。

项目的规划要求必须保留该保护建筑，但允许向南偏东方向移位57米，靠近场地的南边红线，以协调地块的整体发展(见图3b)。民立中学的建筑内部将改造成为精品商业和会所功能，但其外墙面和建筑立面必须保持原貌并且结构体系不得改变，通过整修和加固，使其内部功能能满足时代的要求。

Item	SATWE												ETABS											
	Tower 塔楼T1 (原始设计)				Tower 塔楼T1 (增加一层)				Tower 塔楼T2				Tower 塔楼T1 (原始设计)				Tower 塔楼T1 (增加一层)				Tower 塔楼T2			
	Seismic Action		Wind Action		Seismic Action		Wind Action		Seismic Action		Wind Action		Seismic Action		Wind Action		Seismic Action		Wind Action		Seismic Action		Wind Action	
	地震作用		风作用		地震作用		风作用		地震作用		风作用		地震作用		风作用		地震作用		风作用		地震作用		风作用	
	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y	X	Y
Maximum inter-story drift angle 最大层间位移角	1/885	1/907	1/2392	1/1920	1/832	1/895	1/2246	1/1699	1/679	1/666	1/1092	1/887	1/823	1/862	1/2482	1/2059	1/814	1/867	1/2150	1/1758	1/624	1/658	1/1030	1/1014
Floor location 所在楼层	30	37	29	35	33	38	16	38	34	54	34	54	30	36	29	37	33	26	17	26	18	50	18	54
Maximum inter-story drift ratio 最大层间位移比	1.11	1.31	1.07	1.14	1.15	1.27	1.14	1.15	1.12	1.4	1.05	1.16	1.071	1.182	1.052	1.056	1.12	1.1	1.12	1.13	1.09	1.31	1.11	1.17
Floor location 所在楼层	5	6	5	24	5	6	5	42	6	6	5	6	6	7	6	5	5	5	5	5	6	6	7	6

Table 1. Tower structural displacement (Source: AECOM)
表1. 塔楼结构位移

The above-stated relocation work was successfully executed in early February 2010. This incredible success was attributed to the highly collaborative team work among the client, appointed specialists, consultants and contractor. AECOM team was involved in the entire process and designed the new foundation for the school building.

Office Towers

Tower T1 is 170m tall of 35 storys above ground, Tower 2 is 250m tall of 52 storys above ground. Both towers have 4.2m typical floor to floor height. The towers are designed of reinforced concrete core wall and perimeter composite column system. For Tower T1, one strengthened story with steel outriggers connecting perimeter columns to the core wall and steel belt trusses connecting the perimeter columns is adopted at Level 20. For Tower T2, two strengthened storys with steel outrigger trusses and belt trusses two and three storys tall are adopted at Level 21 & 21M (mezzanine floor) and Levels 36 to 38. Composite floor system with steel H beam and rc slab is adopted. The tower structural systems are shown in Figure 5.

The wind loading for the towers is determined by wind tunnel testing with wind speeds of 50-year and 100-year return periods for displacement and strength checking, respectively. SATWE and ETABS software were used for elastic analysis. Both towers are controlled by seismic activities, not by wind loads. Both towers' structural displacements are summarized in Table 1, all within the code limits of 1/800 for Tower T1 and 1/555 for Tower T2. The structural vibration periods of both towers are presented in Table 2 with the first two modes being translational and the third being torsional. The non-linear elastic-plastic time-history analysis was carried out under a severe earthquake with use of MIDAS Building for Tower 2. Figure 6 indicates the inter-story drift response in the X and Y directions for the three sets of time history records under severe seismic activities. The maximum inter-floor drift is 1/113 which satisfies the code requirement of 1/100.

Shaking table test was carried out for Tower T2 only to verify and supplement the structural performance. The test results indicated:

- Under the frequent earthquake even of the seismic fortification intensity 7.0, the tower structure remained at elastic stage; structural vibration frequency had no change, there was no

道路改道

为便于新地铁车站的施工，位于场地西边的石门一路需要临时改道。利用酒店塔楼群与办公塔楼之间的空间作为临时道路，如图4a所示。这个决定是经过反复推敲和研究确定的对项目的发展影响最小的方案，但是对项目的发展周期以及设计都产生重大影响。临时道路无疑将场地一分为二，其带来的变化如下:

- 对于分开的场地的出入、后勤和施工工作需作重新规划;
- 协调考虑新地铁站与项目的同期施工，以及临时道路下的地库区域施工的滞后。
- 考虑新地铁站完成，石门一路恢复正常使用后，临时道路下的地库设计与施工方案。

结构和技术措施

根据国内的现行规范，本项目的抗震设防强度为7度，设计基本地震加速度为0.10g，场地类别为IV类。重现期为50年和100年的风压为0.55千牛/平方米和0.60千牛/平方米。

民立中学移位

民立中学的结构 (见图3c) 是由中部大厅处的钢筋混凝土框架体系及其他区域的纵横结构承重砖墙体系组成。结构承重砖墙体系的范围包括大厅两边的塔楼以及大厅前后的面积范围。除二层、三层的阳台及四层的塔楼屋面采用钢筋混凝土楼/屋面外，其余的楼/屋面均采用木结构构造，包括木栅栏、木地板、木屋架、木檩条等。结构承重砖墙下设置砖砌条形基础，条形基础下为762-1219毫米厚和1067-1524毫米宽的素混凝土，大厅混凝土柱下设混凝土独立基础，基础底面尺寸为1829 x 1829毫米，独立基础下设置一组1.828米长的木桩。

本项目业主聘请的历史建筑修缮设计专家和移位承建商在项目的早期加入项目组，负责建筑移位设计与施工。经过历时7个月的准备工作，完成了包括对原建筑的完损状况的检测和评定以及结构加固工作。业主、项目建筑师、建筑修缮设计专家、承建商和AECOM团队等主要项目组成员对迁移方案进行技术可行性分析后确定采用斜向直线液压推拉平移法进行移位。这一移位方案的主要技术措施如下:

- 在已加固的现有结构下新做一个钢筋混凝土底盘，底盘下布置托梁，作为迁移的上托盘体系;

Period 周期 (秒) (s)	SATWE			ETABS		
	Tower 塔楼T1 (原始设计)	Tower 塔楼T1 (增加一层)	Tower 塔楼T2	Tower 塔楼T1 (原始设计)	Tower 塔楼T1 (增加一层)	Tower 塔楼T2
1	3.65	3.83	5.64	3.44	3.66	5.74
2	3.10	3.31	5.20	2.98	3.19	4.90
3	2.55	2.54	3.64	2.43	2.54	3.71

Table 2. Tower structure period (Source: AECOM)
表2. 塔楼结构周期

cracking or plastic deformation observed on the structure. The max inter-story drift in X-direction occurred at 51– roof floors; the one in Y-direction at 46-50 floors, less than the code limit of 1/555.

- Under the fortification level earthquake, structural frequency and stiffness appeared slight declination, however no cracking nor plastic deformation was observed; the structure remained in elastic status in general.
- Under severe earthquake event, cracks appeared in the structure. Structural frequency declined subsequently. The max inter-story drift occurred at 51 – roof floors in X-direction, being 1/126. The outrigger and belt trusses appeared largely intact without apparent failure. Cracks appeared on the slabs surrounding perimeter columns as well as the edges of some lintel beams at the core. More serious whiplash effect was observed on the top floors.
- Under extremely severe earthquake of seismic fortification intensity 8.0, the core wall stayed intact. Some of lintel beams failed. Cracks appeared on the slabs surrounding the perimeter columns and edges of lintel beams. More damage was observed on the floors above and under the strengthened floors with outriggers and belt trusses.

Above all, the test results have proven the chosen structural design to be sound and efficient. The optimization suggestions have been adopted in the design including reducing the thickness of core wall to appropriately tune down the lateral stiffness of the core wall; improving the ductility of lintel beams of the core wall and improving the stiffness and ductility of the floors above and below the strengthened floors as well as the top floors of the building.

Pile foundation of 850mm dia. cast-in situ r.c. bored piles with raft pile cap is adopted for the towers. T1's pile raft is 3.7/3.15m in thickness, T2 is 4.75/4.2m in thickness. C50 concrete is used. The bored piles using C35 concrete are of 55m in effective length with bearing capacity of 4,900kN. To ensure mitigation of the two tall towers' impact to the adjacent metro tunnels, an average pile capacity of 300 tons has been incorporated as an additional criterion to all the piles under the towers.

Finite element analysis with use of PLAXIS was conducted in early 2011 to estimate the settlement of the metro station caused by construction of the two office towers. The result of the analysis indicated that the settlement of the metro station induced by the construction of the two tower buildings T1 and T2 were 19mm and 18.9mm, respectively, which satisfies the metro bureau's requirement of 20mm. The same analysis was reviewed and updated in late 2013 to incorporate construction program changes including one year deferred metro station construction program and associated status of T1 and T2 construction. Tower T2 is constructed earlier than Tower

- 在所设计的斜向平移通道处的地面上埋设不锈钢的地梁做为滑移面，作为过渡段，下滑梁及联系梁等组成下底盘体系。下滑梁的顶面找平后铺钢板;
- 在上托盘体系与下底盘体系的梁间安装液压千斤顶和移动装置;
- 在新规划的位置做好新址的桩基及桩顶转换筏板;
- 在对现有结构完成必要的安全加固后，在上托盘体系与下底盘体系之间把建筑物与基础切断脱开，通过液压悬浮推拉方式，采用PLC控制及监测系统，迁移建筑物到达新的预定位置;
- 使建筑物与新桩筏基础固定连接，在连接处设置隔震支座以减少未来新址处的施工对建筑物的影响;
- 未来将对位于新址处的保护建筑物下的地下室采用逆作法进行施工。

上述建筑物的整体平移工作于2010年2月初顺利完成，这一卓越的成功源于整个项目组精湛的团队协作和创新的技术方案。AEOCM团队参与了整个过程并且设计了新址建筑的桩基础及桩顶转换板。

办公塔楼

塔楼T1地上有35层、170米高，塔楼T2地上有52层、250米高。两座西塔楼的典型层高为4.2米。两塔楼均采用钢筋混凝土核心筒和钢混凝土柱外框架抗侧力体系，塔楼T1在20层设置了钢伸臂桁架和连接外框架柱的腰桁架组成的加强层。塔楼T2设置了两个加强层，一个在21层及21夹层，另一个在36至38层，两个加强层均设有钢伸臂桁架和腰桁架。楼面系统采用H型钢梁及现浇钢筋砼组合楼板。图5所示两个塔楼的结构形式。

风洞试验确定了两个塔楼的风荷载，以50年和100年重现期的风压值来检验建筑物的位移和强度。采用SATWE和ETABS对结构进行弹性分析，两个塔楼均是地震控制，风荷载不起控制作用。结构的位移汇总于表1中，塔楼T1和塔楼T2的最大层间位移角均在设计规范限制值1/800 和1 /555之内。两个塔楼结构的自振周期见表2，前两个振型为平动，第三振型为扭转。采用MIDAS对塔楼T2进行了罕遇地震作用下的非线性弹塑性时程分析，图6显示了三组时程波分析得出的结构整体在X和Y方向层间位移角的分布，最大层间位移角为1/113，满足规范1/100的要求。

针对塔楼T2还进行了振动台实验以求验证和补充结构性能。实验结果表明:

- 在7度多遇地震作用下，结构处于弹性阶段，结构自振频率未发生变化，结构没有开裂、塑性变形等破坏现象，X向层间最大位移角发生在51层-屋面，Y向层间最大位移角发生在46-50层，均小于规范1/555的限值。
- 在7度基本烈度地震作用下，结构自振频率和刚度稍有降低，但没有可见的开裂、塑性变形等破坏现象，结构基本处于弹性阶段。
- 在7度罕遇地震作用下，结构出现开裂，结构自振频率进一步下降。层间最大位移角发生在X向51层-屋面，为1/126。核心筒、加强层伸臂桁架及腰桁架外框架柱基本完好，没有明显破坏现象。楼板与外框架柱以及楼板连接处以及核心筒连梁端部出现裂缝，结构顶部的鞭梢效应较严重。
- 在8度特大罕遇地震作用下，核心筒墙体基本完好。核心筒中部分连梁发生破坏，连梁端部出现裂缝，外框架柱与楼板交界处的楼板出现裂缝，加强层上下层外框架柱与楼板交界处的楼板的破坏较其他楼层严重。

T1. The result of the re-analysis as shown in Figure 7 indicated that the relative settlement of metro station impacted by Tower 1 construction is 18.0mm while by Tower 2 is 16.4mm, both are better than the results derived in 2011. It is concluded that the deferral of the completion of the metro station is beneficial to the settlement induced by the prevailing tower construction.

A Major Design Change to T1

A major design change to T1 has been initiated by the client during the construction stage with an intention to reduce the typical floor height from 4.2m to 4.1m so to add an extra floor to the lower part of the building within the original height of 170m. To maintain the normal construction of piled foundations structural appraisal was conducted firstly to the originally designed foundations. It was found that the original pile capability can sustain the additional loads imposed by the additional one floor. The design of raft pile cap was re-assessed and revised based on the structural analysis results. Original construction program would be maintained whilst detailed structural re-design on the tower structure has to be undertaken within a fast track time frame. The structural deflections and periods with the additional floor are summarized in Table 1 and 2.

The revised structural design has gone go through necessary statutory re-submissions.

The Auditorium Structure

The three-story auditorium building is planned to be built on top of the tunnels of Metro line 2. Steel frame structure is chosen for the building with steel rectangular columns and H section steel beams. Composite floor system with steel beam and rc floor slab is adopted. Columns as well as supporting piles are precisely located and agreed with the metro bureau in consideration of minimal impact to the metro tunnels under. Figure 8 shows the structural arrangement.

To mitigate the vibration impact from the metro tunnel to the building and ensure the building with reasonably livable condition, Anti-vibration measures have been adopted for the building. On site measurement of vibration has been conducted by the appointed acoustic specialist for this project. The grade of vibration at L1, L2 and L3 was found as 89.27dB, 87.27dB, and 85.27dB respectively, which has exceeded 17.27dB max in comparison with the latest acceptable standard of 72dB in Shanghai. Two feasible options have been explored and studied by the appointed acoustic consultant, namely the Elastomer Structural Bearing and the Spring Box. A proprietary product namely CDM-CHR-SPRING BOX, have been finally chosen with specified min mitigation degree of 25dB. The Spring Box is designed to be installed in between the foot of column and the raft pile cap. The design for the installation of the Spring Box has been an interactive and collaborative process among the structural consultant AECOM and the appointed acoustic consultant & supplier of the device.

The raft pile cap is divided into 59 pieces as shown in Figure 9. The 59 pieces of alternatively designed steel cages have been pre-fabricated and delivered on site in advance by the main contractor. Construction of each piece from excavation, placing the steel cage in place and in turn concreting ought to be precisely completed within 7 hours from mid-night to early morning when the metro operation halts. Monitoring of tunnel movement has been carried out throughout the entire construction process, monitoring data was reviewed by the metro bureau and the project team. The essential elements for the success of the design and construction are summarized as follows:

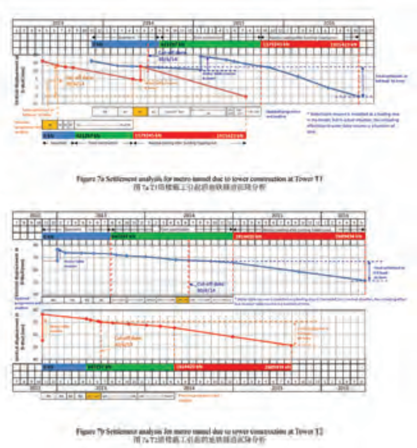

Figure 7. Settlement analysis for metro tunnel due to tower construction (Source: AECOM)
图7. 塔楼施工引起的地铁隧道沉降分析

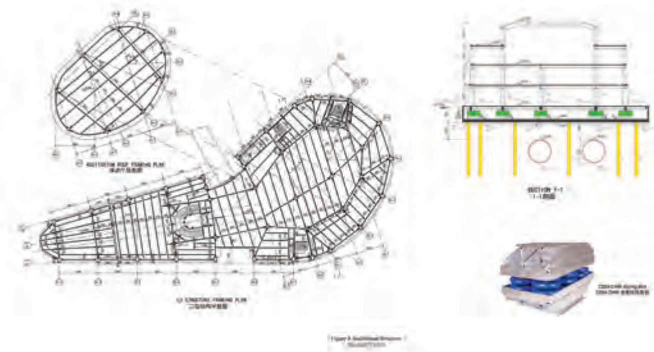

Figure 8. Auditorium Structure (Source: AECOM)
图8. 演讲厅结构

Figure 9. Raft Pile Cap of Auditorium Building (Source: The Project Client)
图9. 演讲厅结构桩承台

综上所述，振动台实验结果足以证明确认塔楼整体结构合理有效，满足规范7度抗震的设防要求。其所建议的结构优化措施亦在设计中予以采纳: 包括适当减小核心筒墙体厚度以适度减小核心筒抗侧刚度，适度提高核心筒中连梁的延性，增加加强层相邻楼层构件的刚度和延性，及适当增加顶部楼层的强度和延性。

塔楼采用850毫米直径的钻孔灌注桩—平板式筏板基础。T1塔的筏板厚度为3.7/3.15米，T2塔的筏板厚度为4.75/4.2米，混凝土强度为C50; 桩混凝土强度C35，有效桩长55米，单桩承载力特征值为4900千牛。为确保减少两个办公塔楼对邻近地铁隧道的影响，塔楼下的实际布桩的平均承载力取用300吨的更严格措施。

于2011年初采用PLAXIS进行有限元分析两个办公塔楼的施工所引起的地铁隧道的沉降量，分析得出塔楼T1和T2对地铁隧道产生的沉降量分别为19毫米和18.9毫米，在地铁规定的20毫米范围内。

1. Design integrates with construction methodology throughout the entire design process. Designer shall study and consider constructability and propose feasible thoughts and measures
2. Collective innovations as expressed above resulted from a great deal of team work among all the participant parties including the client, design architect, structural consultant, the Metro bureau advisors, the appointed metro liaison expert, the local Design Institute and the main contractor through rounds of brainstorm sessions, analyses, reviews and discussions.
3. The excavation and foundation construction on top of metro line 2 tunnels have been comprehensively planned, approved by the relevant authorities and finally executed with extreme caution and effective measures within the above-mentioned assigned construction time slot.

Top Down Construction

Top down construction for the area where the temporary road is located, as shown in Figure 4b, has been decided by the client due to time saving in the overall construction program for the basement structure and MEP services installation as well as less vibration and settlement impact to adjacent existing buildings and less impact on the air quality of the neighborhood area from environmental sustainability perspective. The re-design for the piled foundation and basement structure with the affected area was undertaken with fast track program. The design for the top down construction methodology has been concluded after rounds of communications with the client and the contractor. Costing analysis in the meantime has been exercised so to manage from both the time and cost perspectives. Cast in-situ bored piles of 1,000mm dia. are designed to support and cater for the installation of steel stanchions in the form of 450mm dia. circular steel section. Ring beam is adopted at the column and basement floor beam connection to sustain substantial punching shear force and achieve better interconnection at the joint. Figure 10 illustrates sequence of top down construction and relevant connection details.

The Construction Program

Phased construction program has been planned in response to the development constraints as well as the client's development plan. The entire construction is planned into three major phases: Phase one consists of two tall office towers and the corresponding basements; Phase two comprises three hotels buildings; and Phase three comprises the podiums and the associated annex buildings.

The whole site has been divided into 13 zones as shown in Figure 4b. A clear time table versus construction activities has been defined for each zone from excavation through sub-structure construction to completion of superstructure construction. The detailed program has facilitated all the parties of the project to tailor make their own work plan and review respective achievement accordingly. To facilitate construction activities on site, a comprehensive monitoring program has been implemented. Regular measurement of ground movement and adjacent existing building movement as well as ground water level during the course of the construction has been carried out and reported in centralized manner to all the relevant parties. Safety is of the highest priority to the project team and pre-cautionary measures have been regularly reviewed, checked and reinforced if any adverse alert or observation is raised. Remedial solutions has been sought and determined with the

随着地铁站施工进度推迟约一年的时间和塔楼T1和T2施工的实际实施，塔楼T2的施工期超前于T1塔，于2013年12月对上述分析进行更新 (见图7) 。分析得出塔楼T1的施工引起的地铁隧道的净沉降量为18.0毫米，塔楼T2的施工引起的净沉降量为16.4毫米，沉降值均小于2011年的分析结果，这表明地铁站施工的延后及两个塔楼的现行施工计划对控制地铁隧道产生的沉降是有利的。

T1 塔楼的设计变更

在项目进入施工阶段业主方决定对塔楼T1的设计进行调整。将原4.2米的层高降为4.1米，在低区增加一层，原170米的高度保持不变。结构上首先对原设计的基础进行评估，通过分析发现，原设计的桩基础能满足增加一楼层的整体受力情况，桩承台筏板则需重新进行分析和修改设计。原定的基础施工计划不受影响，但对上部结构的重新分析和设计必须同步快速进行，结构位移和自振周期结果汇总于表1和表2。

修改后的设计重新进行各项相应的设计送审。

演讲厅结构

在地铁2号线上方规划了一座三层高的演讲厅建筑，其结构采用钢框架结构体系，由矩形钢柱和H型钢梁组成，采用钢梁及现浇钢筋混凝土组合楼面体系。柱子及柱下桩基的定位必须考虑与现有地铁隧道的关系，对现有地铁隧道的影响最小，并且获得地铁部门的确认。图8展示了演讲厅结构平面和剖面图。

为减小地铁振动及二次辐射噪音对上盖建筑正常使用的影响，防振措施必须在设计中予以考虑和采纳。项目聘请的声学顾问对现场振动测试的数据显示，在一、二、三楼预测振动级 (日间) 分别为89.27分贝，87.27分贝和85.27分贝，均已超出上海市2010年新规定的限制72分贝 (日间)，声学顾问对两种可行的隔振方案进行了深入分析和比较，即: 采用弹性体结构支座和预压钢弹簧箱减振器，最终确定选用专项产品CDM-CHR钢弹簧箱减振器，其最小减振量为25分贝。钢弹簧箱的安装位置设在柱与桩承台的连接处。钢弹簧箱减振器的安装设计是在结构性顾问AECOM团队和业主所聘请的声学顾问及设备供应商的协作下成功完成的。

设计上将桩承台分割成59块，如图9所示。总承包方对这59块筏板的钢筋笼进行了替代设计，经场外预制后运往场地供施工使用。由于地铁运行的限制要求每一块桩筏板施工从开挖，置放钢筋笼及浇捣混凝土必须在深夜至早晨地铁停运的7个小时内完成。在整个施工过程中对隧道的位移进行连续监测，测量数据由地铁部门及项目团队审阅。总结本建筑结构设计和施工成功的决定性要素如下:

1. 设计和施工的一体化是个动态的过程， 设计方在设计中需要研究和考虑可施工性， 提出可行设计思想和方法。
2. 在施工方提出施工方案后，设计方与施工方的沟通和协作是必要且关键的。设计的灵感与创新来自于设计和施工的高度融合，最佳的解决方案一定综合了业主和地铁部门的要求， 是集各方顾问的智慧和建议之所长而决定的。
3. 虽然位于地铁2号线隧道上部的地基开挖和基础施工经过了精心的施工组织计划并获得了相关部门的批准，但要在上文提及的时间窗口内完成施工，最后非常谨慎、有效且准确地实施亦是必不可少的。

逆作法施工

业主方决定临时道路区域下的地下室采用逆作法施工 (见图4b)，这一方案的决定是基于对地下室结构和机电系统安装总体施工周期的减少，减小了对附近现有建筑的振动和沉降影响，以及从环保方面考虑减小对周围街区空气质量的影响等诸多因素权衡决定的。结构上配合逆作法施工对桩基础和地下室结构进行了重新

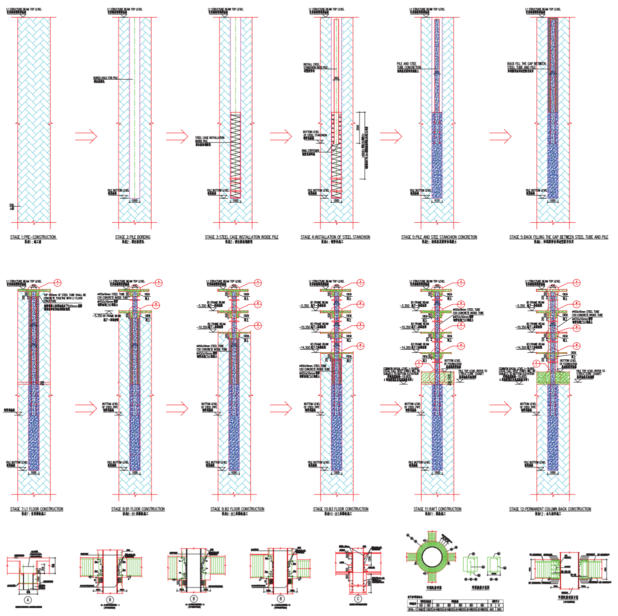

Figure 10. Sequence of top down construction and details (Source: AECOM)
图10. 逆作法施工顺序和大样

strong leadership from the client's project management team as well as all the parties' participation and contribution.

The current status of the project as shown in Figure 11 has reflected tremendous achievement from the entire project team. Continuous commitment will drive the success of the project.

Collaboration Between Design Team and Site Team

A team of full time resident structural engineers has been deployed on site since the commencement of construction works. The key duties and responsibilities of the site team are assigned to assist the client team to manage the construction activities to the planned program, monitor site progress, safety and quality and submit RE's regular report and raise adverse observation to the client and relevant parties. On the other hand the site team is responsible to liaise and coordinate with the structural design team on design matters and seek design clarification and provide supplementary design information from the design team to contractor, and assist the design team to coordinate and monitor contractor's material and detailed design submissions. A daily three work shift and seven days per week is the working pattern, site diary has been maintained on site and reported to the project manager and director internally. Regular meeting between design team and site team has been conducted to share and update with the entire team on all the key activities and work plan with key action tasks.

Conclusion

A new level of design and construction integration has been executed in Dazongli mixed use development project in response to its complexities and challenges. It is the highly interactive integration which has inspired and motivated professional designers to attain innovative thoughts and new approach with efficiency, smartness, time and cost effectiveness in mind.

Figure 11. Site Photos (Source: The Project Client)
图11. 现场图片

设计，在经过了与业主和施工单位的多次交流后确定采用逆作法的施工工艺，并配合造价分析，供业主了解对时间和造价方面的影响。与施工方和基坑开挖顾问研究和讨论逆作法施工顺序及施工方法，研究和设计临时及永久工况下结构支柱，结构梁，与梁柱连接节点等。结构设计采用1.0米直径的钻孔灌注桩支撑450毫米直径的圆钢支柱，在结构支柱与地下室楼层梁连接处设置环形梁，以承受连接处较大的冲切剪力和便于更好的连接(见图10逆作法施工的顺序和相关连接节点的示意图)。

施工计划

本项目考虑相应的发展限制条件制定了分阶段的施工计划。整个施工分为三个主要阶段:阶段一包含两个办公塔楼和相应的地下室区域;阶段二包括三个酒店塔楼;阶段三为裙楼。

整个场地划分为13个区域，如图4b所示，每个区域都制订了详细的施工内容和时间计划。同时计划并实施了全面的观测和监控计划，包括对地面沉降、现有楼宇的位移、地下水位标高等全面的观测和监控。安全是本项目的首要重视方面，在业主的领导下定期讨论、检查和加强预防措施。

图11显示了项目当前的状况。整个项目团队将继续协作以达至项目的圆满完成。

设计与驻工地团队的协作

根据项目要求自施工伊始驻工地结构工程师团队便开始进场参与工作，驻工地团队的主要职责包括:协助业主团队管理施工事项，监管工程进度、安全和质量，并定期提交报告;该团队还负责联络设计团队、与设计团队协调的设计事项和出图计划、寻求设计澄清和资料、协调和监督承包商的设计报审计划与实施。每日三轮班，每周7天工作制;在施工现场保存现场日志并向内部项目总监和项目经理报告;结构设计组与驻工地团队定期召开会议，共享和更新主要事项及工作计划。

结语

由于本项目的复杂性和挑战性，一个全新高度的设计与施工一体化实施于项目的过程中。正是高度的一体化带给了专业设计师动力和启发，从而产生效率、智慧和节省时间和成本的创新思想及解决方法。