COLLINEAR FORCE AND FREQUENCY ANALYSIS OF A VIADUCT PILE FOUNDATION CONSTRUCTION PROJECT: A CASE STUDY ON THE APPLICATION OF BIM TECHNOLOGY

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Abstract. For designers, construction technologists and management personnel, BIM technology allow working more conveniently, swiftly, efficiently, accurately, timely and in a more coordinated manner. These days, China is experiencing rapid economic growth and high population dynamics, resulting in worst traffic congestions, which demands to strengthen the urban transportation infrastructures, of which the railway viaduct is the most common practice. Such viaducts are built in and around most subways. A domestic viaduct project was designed and constructed in Wuhan City. This project faced some new problems and complications in the design and construction phase. An *Autodesk Revit Architecture*, *Ansys*, and *Structural Bridge Design* were used on a BIM platform to study and design this viaduct pile foundation project. The collinear force difference dynamic analysis was conducted using BIM technology as one component of the entire project. Combined station house and viaduct construction deformation and frequency analysis were summarized and evaluated at different weak deformation locations of the viaduct pile project. Early support structures were implemented for tunnel support based on the proposed drill (mine) tunnel deformation monitoring scheme designed during BIM simulations. In the progress of the subway tunnel construction process, unusual circumstances observed during analysis were used as an immediate feedback for construction, supervision, and design of the relevant units, and appropriate support measures were taken to strengthen the tunnelling and piling process. Using BIM technology, the total construction process was optimized, as well as an enhanced system management was realized so that each system components and building steps were clarified during operation. Due to the high linearity of the structure, there were certain difficulties in installing and building the viaduct and the viaduct curves of the station. Based on the feedback from the BIM simulations, n-shaped door frame support structure system and accurate installation of steel box girder were used at the subway station structure of each component to meet the national and international safety standards.

Keywords: BIM, viaduct, dynamics, collinear force, tunnel, pile.

1. Introduction

Results of social, economic and scientific research are being used to promote the social progress and the development of technical infrastructure in a country [1].The objective of the 21st century, regarding the construction technology, is to make use of BIM (Building information modelling [2]. BIM enables to connect intelligent 2D and 3D objects to a virtual architecture database [1; 3]. All phases of the building lifecycle (planning, design, construction, operation, maintenance, and control) are encompassed in BIM [4; 5].

This case study was conducted on a building project in Wuhan Railway Transit Line 3 Phase which extends from Wangjiawan Station to Zongguan station. The project encompasses the Wangjiawan Station; Planning Qintai Longyang Road elevated road segment parallel to Longyuang Road towards to Wangjiawan station via the path beneath the Rose Street, vertically through the Song of the Streets raised way, into the Han River, to reach Zongguan station. The plane positional relationship between the Longyang Road overpass, the Wangjiawan Station and the line leading to Zongguan station are shown in Fig. 1.

During the construction phase, Longyang Road viaduct pile foundation construction must be completed before the subway tunnel construction, so as to ensure the structural safety of each other [6; 7]. But the current construction progress of Longyang Road, behind the elevated subway tunnel construction, has 303 m tunnel to the direction of shaft excavation towards Wangjiawan Station (surface passed through Rose Street, reaching Longyang Road Viaduct Pier L-05 position).The direction of the shaft to Zongguan Station is excavated 207m (surface has to Qintai Avenue). Late Longyang Road viaduct pile foundation construction have completed the initial geological study that can support the subway tunnel section, without a lot of risks [8]. Based on the current construction progress: Longyang Road overpass, viaduct, and the Longyang Road subway tunnels were analyzed using BIM platform [9; 10]. Longyang Road Viaduct Pile Foundation Construction study and the initial impact of the case-drilling (mining) method of the supporting structure of the subway tunnel section were completed and accordingly safest construction of the protection and control measures were proposed [11; 12].

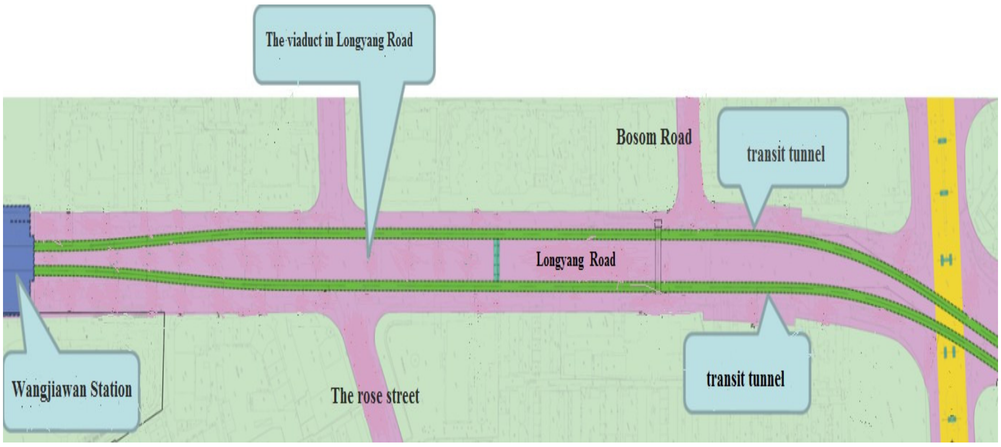

Fig. 1. **Schematics of Wangjiawan Station and Zongguan concerning Longyang Road station intervals overpass plane location**

2. Methodology

BIM technology is a cocktail of on-desk application of civil work software and mathematical algorisms for real-time decision making. The current project used the following: Autodesk Revit Architecture, Ansys, Structural Bridge Design.

2.1. 2.1 Phases of construction

Pile Foundation Construction of Superstructure and proposed construction is divided into three paragraphs (Fig. 2).The beginning and ending points of the first section of the project is LYK0+180 to LYK1+340 (project start to Hanyang Road, including Song of the Streets Road). The second section includes LYK1+340 to LYK2+160 (from Hanyang Road to Ink of Hubei Road including Hanyang Avenue). The third segment starts from LYK2+160 to LYK3+614.25 (from Hubei Road to Hunan Road, including Ink of Hubei Road) (Fig. 2).

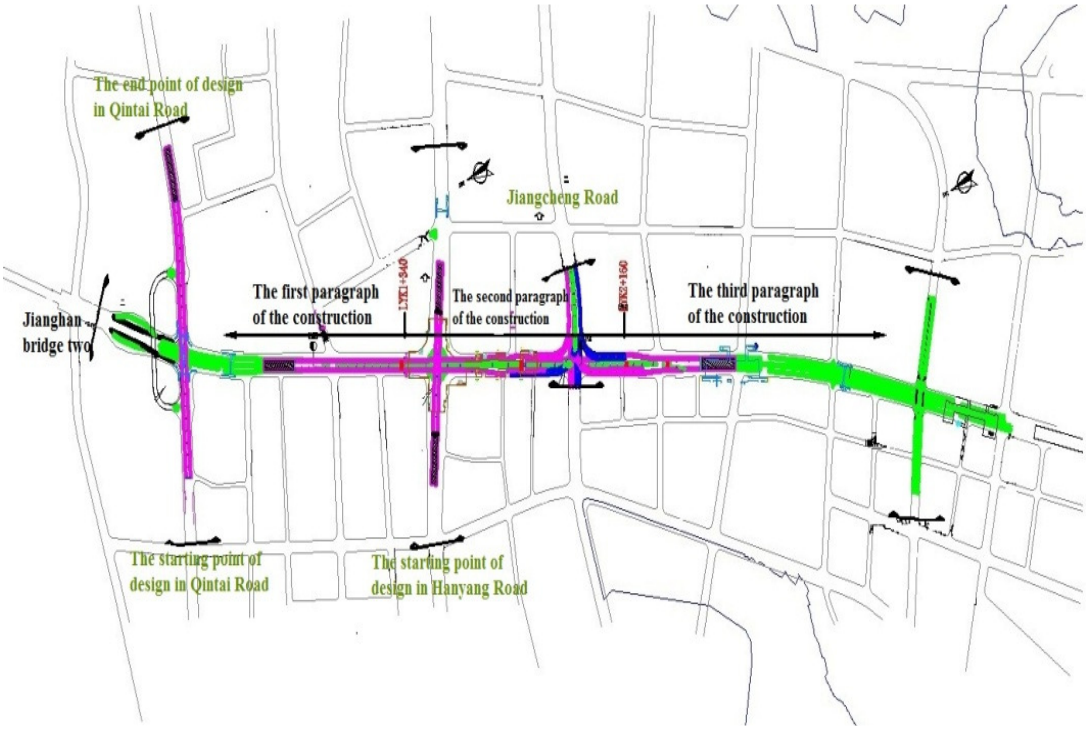

Fig. 2. **Partition of floor plan**

The project in the construction phase of the pile construction enclosure has a set width of 11m, arranged along the center line of the road following the pre-existing road traffic sidewalk [13; 14]. The pier locations under each paragraph of the construction phase are presented in Fig. 3. For further clarity, the virtual schematics of the tunnel and the pier model used in the BIM interface is shown in Fig. 4.

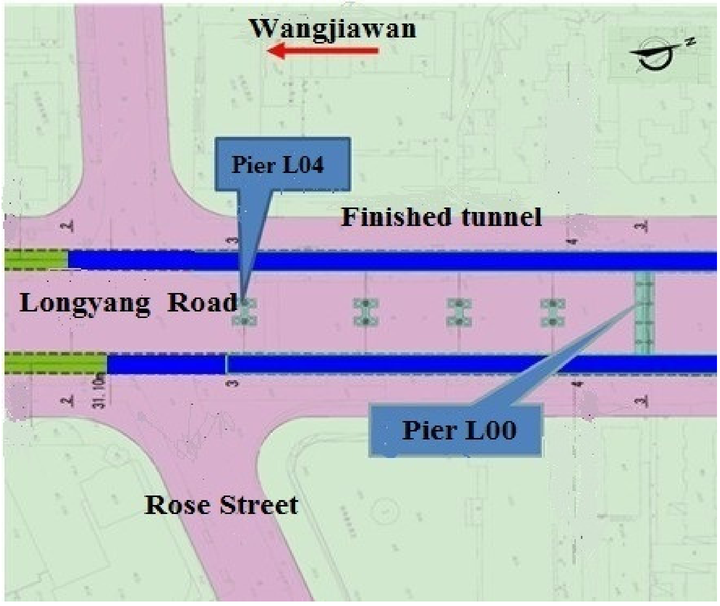

Fig. 3. **BIM simulation pier locations and tunnel construction**

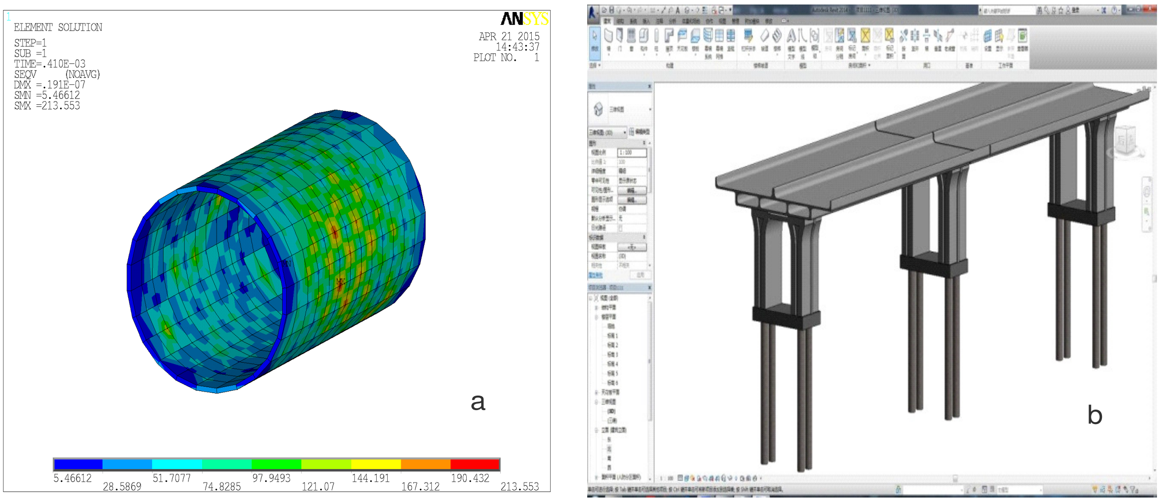

Fig. 4. **The main tunnel (a) and Pier model (b)**

Impact drilling method as presented in Fig. 5 was practiced erecting the piles.

2.2. Model setup

The finite element method was employed to simulate impact in a limited area. Taking into account the excavation of the tunnel only within a certain range of dynamic characteristics, further away from the excavation site, the smaller is the impact and considered negligible [15-17].Excavation at a distance of three times within the span of its main power less than 5% change in the distance five times within the span of the excavation, its main driving force change of 1% or less [18, 19]. Based on this theory, finite element analysis can be controlled within this range, and in the boundaries of the range [20, 21]. Data for this calculation is as follows: Bridge pile depth of 25.0m, pile diameter of 1.6m, pile spacing of 2.8m, bridge piles from the tunnel l2.7m, tunnel span of 6.4m, depth of 25.2m, a diameter of 6.0m. According to the above conditions, the length of the model in the X-direction is considered as 20.0m, a width of 10m in the Z-direction (to the tunnel), and Y-direction (height of the model) is 75.0 m. Analysis using finite element calculations, the initial tunnel support use 63 units of elements, and the soil stratum was modeled using 45 units of elements, and the piles using plane elements of 42 units. For the model units: see Fig. 6a for the tunnel and Fig. 6b for the bridge piles position dividing unit.

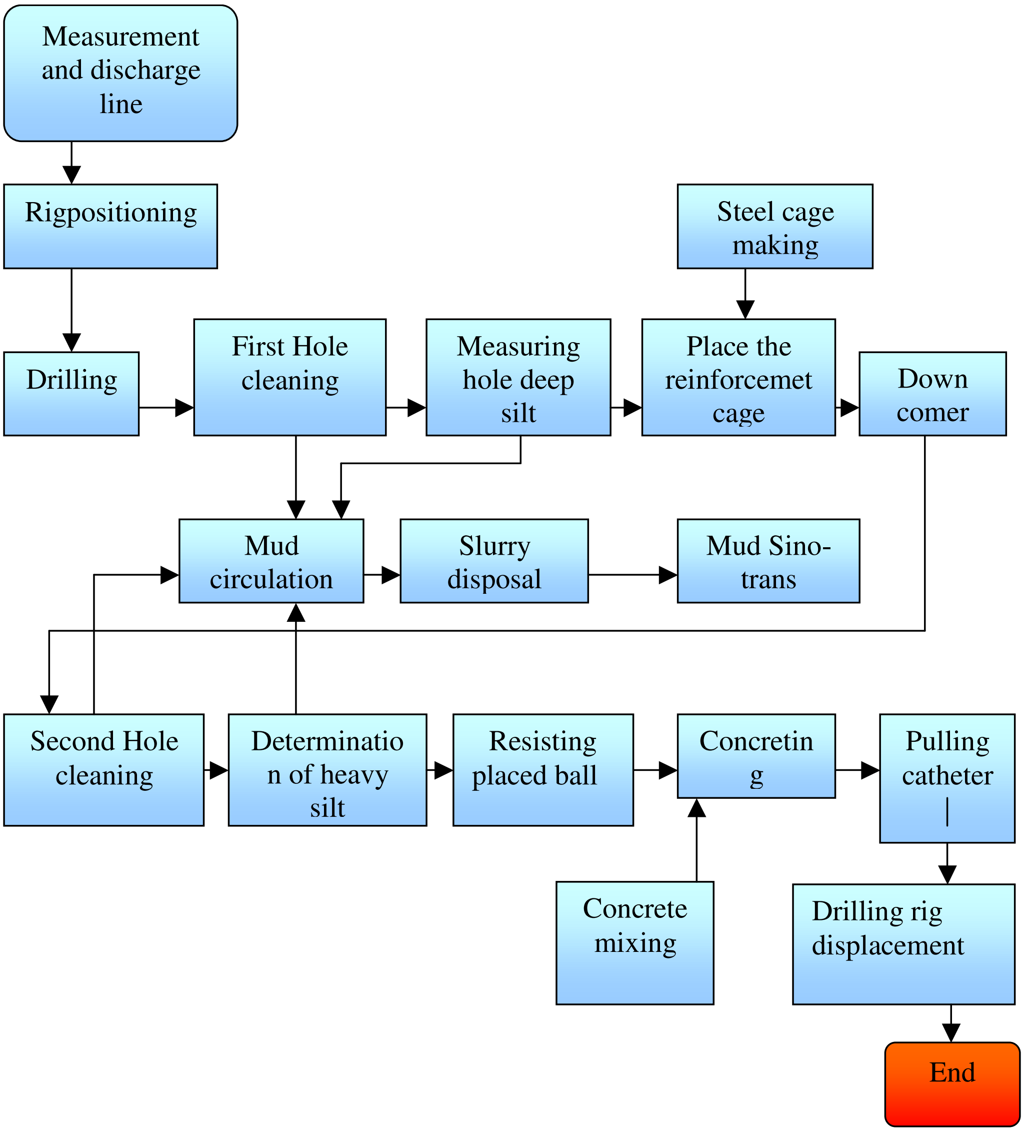

Fig. 5. **Impact Drill Hole Pile Construction flow chart**

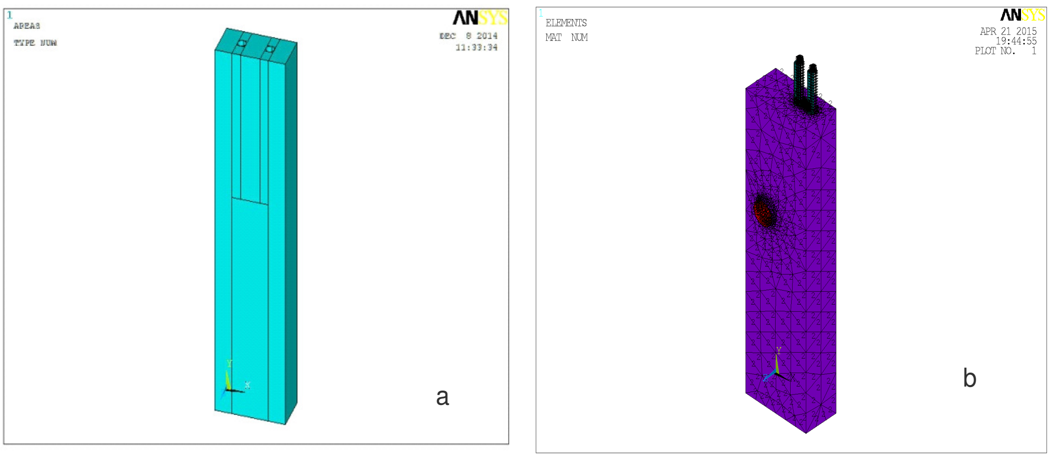

Fig. 6. **Model unit (a) and Tunnel and bridge piles position dividing unit (b)**

2.3. Geological attributes and piling procedures.

The log analysis depicted that the top geological formation is composed of silt clay soil [22]. The underlining strata are made from weathered limestone. Between the limestone layer and the top silt clay surface, the geology changes to clay soil (Fig. 7). The Tunnel is completely lying in the clay stratum. The geological parameters were changed accordingly at each stratum during simulation.

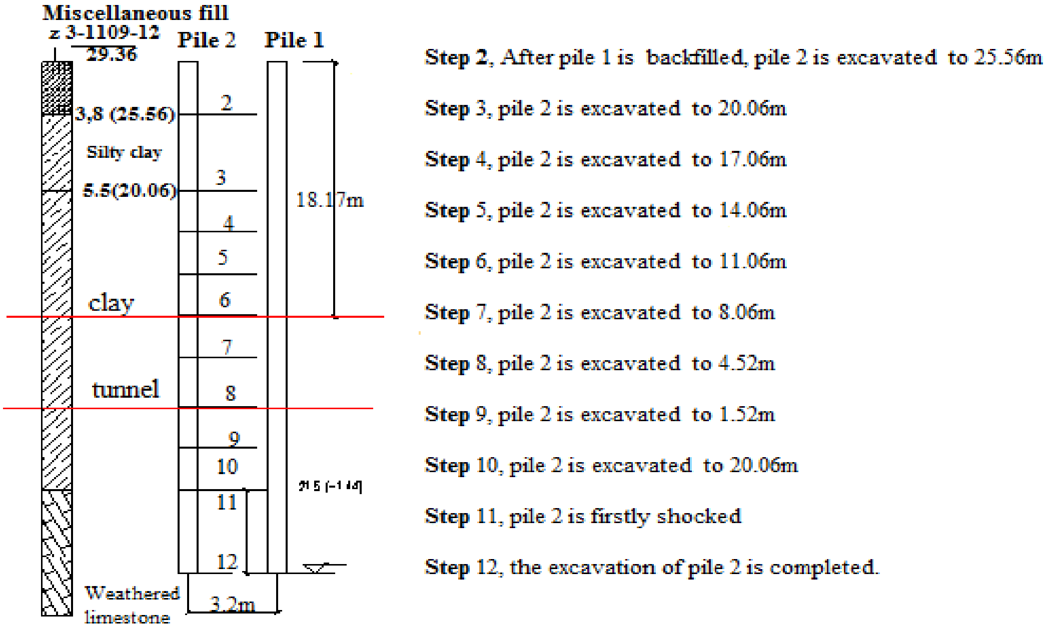

Fig. 7. **Pile schematic construction process simulations**

3. Results and Discussions

3.1. Tunnel Lining moment, shear, axial force analysis

The dynamic characteristics of the tunnel lining analysis considering the first 20m to 30m range segment was computed and the initial support moment's hear, band axial force at all stages are presented in Fig. 8 and Table 1.

Table 1

Initial Support moment shear Axial Force on table

Project Phase	Simulated parameters		
	Maximum moment, kN·m	Maximum shear, kN	Maximum axial force, kN
Stage 1: Piles Construction completion	159.74	197.96	1385.46
Stage 2: Piles Construction completion	166.40	201.15	1402.13

According to the data analysis, as presented in Table 1, bridge piles during construction of the initial support of influential tunnel moment was increased by 4.1%, the greatest impact: the shear and axial force increased about 2% or less which is relatively small. Considering the strength and size; the construction bridge piles initial tunnel support can withstand the loads caused without causing much impact.

3.2. 3.2 Deformation Analysis of Tunnel Lining

Similarly, when the tunnel lining segments from 20m to 30m range was simulated, the displacement of the initial support at different stages in the Y-direction (tunnel height), X-direction (tunnel width), and the lining of the overall displacement results are presented in Fig. 9 and summarized in Table 2.

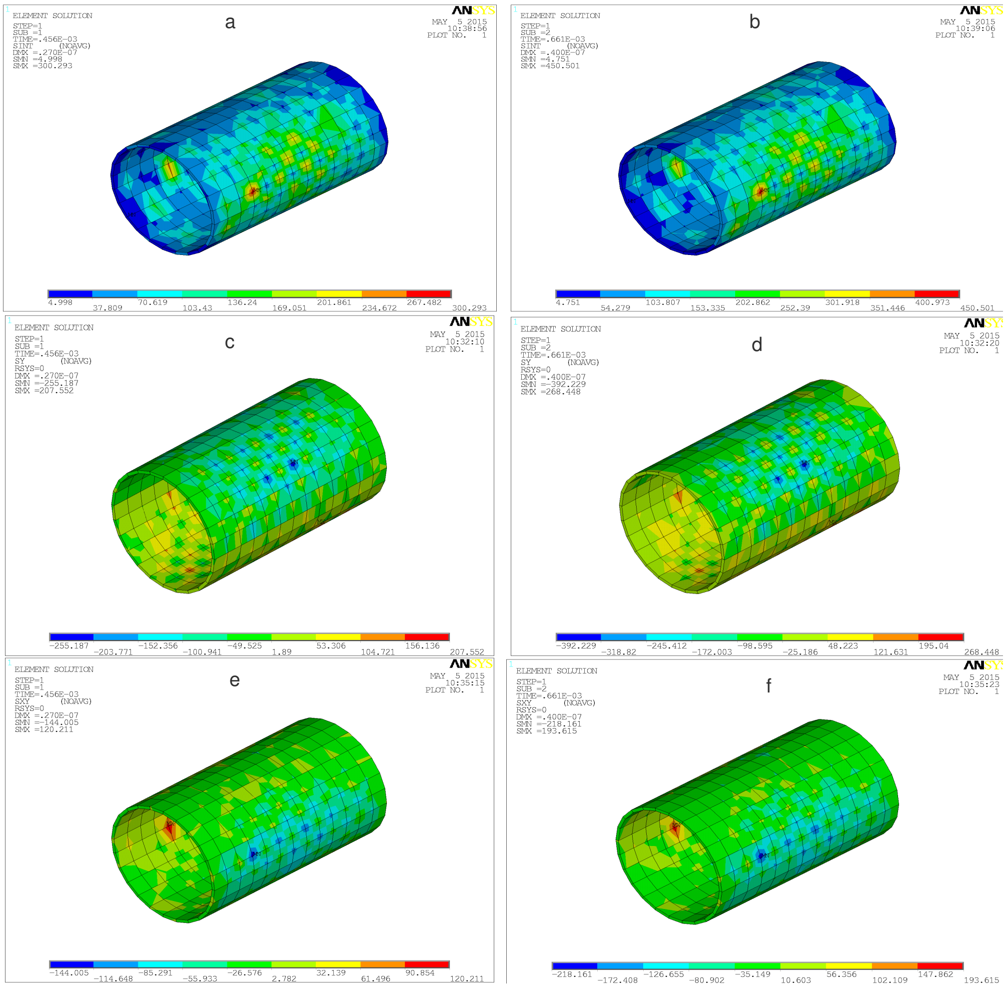

Fig. 8. **After construction is completed pile 1 Lining moment cloud (a), After completion of construction of pile lining 2 moment cloud (b), After construction is completed pile 1 shear lining cloud (c), After completion of construction of pile lining 2 shear cloud (d), 1 pile shaft lining after construction contour plots (e), After completion of construction of pile lining 2 axis contour plots (f)**

According to the data analysis (Table 2), the bridge pile in the construction phase have an impact on the initial support of the tunnel in the X-direction being taken place 1.39 mm hole converge pile bridge construction, increased by 20.4%. Timely and effective protection measures have been taken during construction bridge piles r to ensure the initial tunnel support will not cause much impact.

Table 2

Initial Support displacement

Project Phase	**Simulated parameters**		
	Z-direction of maximum subsidence (mm)	**X-direction of maximum displacement (mm)**	**Combined maximum displacement (mm)**
Phase-1 pile construction is completed	13.63	2.82	13.99
Phase-2 pile construction is completed	14.23	3.07	14.58

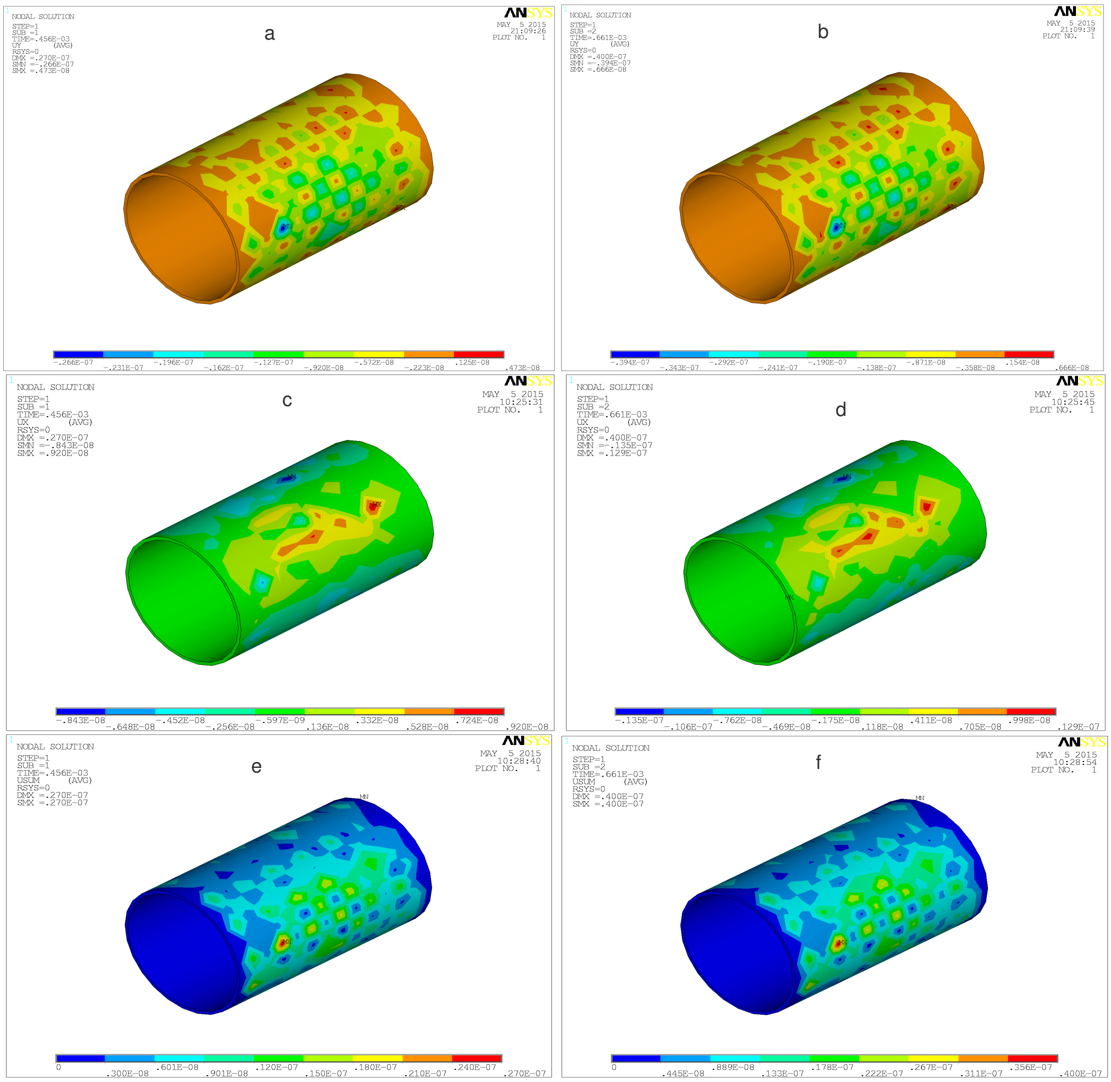

Fig. 9. **Pile construction is completed stage 1 Lining Y direction displacement contours (a), pile construction completed Phase 2 Lining Y-direction displacement (b), pile construction is completed stage 1 Lining X-direction displacement contours (c), pile Phase 2 construction is completed lining X-direction displacement contours (d), pile Phase-1 construction is completed lining combined displacement contours (e), pile Phase-2 construction is completed lining combined displacement contours (f)**

3.3. Bridge Pile whole process analysis

Through the entire process of piles construction, detailed simulation of the frequency response of the soil around the tunnel was evaluated once at each time step of 3m excavation. The results are summarized in Fig. 10.

From the above figure (Fig. 10), at step 3 (11.08 m) resonance occurred when the natural frequencies of L0 pile Excavation and Tunnelling excavation exhibited an intersection, that indicated the use of appropriate control measures until the excavation of the limestone formations completed, preventing the tunnel producing a big impact. It is mainly due to the density and elastic modulus of concrete to soil produced extrusion. In such conditions, the construction should pay attention to the process and take appropriate measures. In L1~L5piles, the fundamental frequency and tunnel excavation pile frequency interval influence each other less. However, it requires the use of appropriate control measures when necessary.

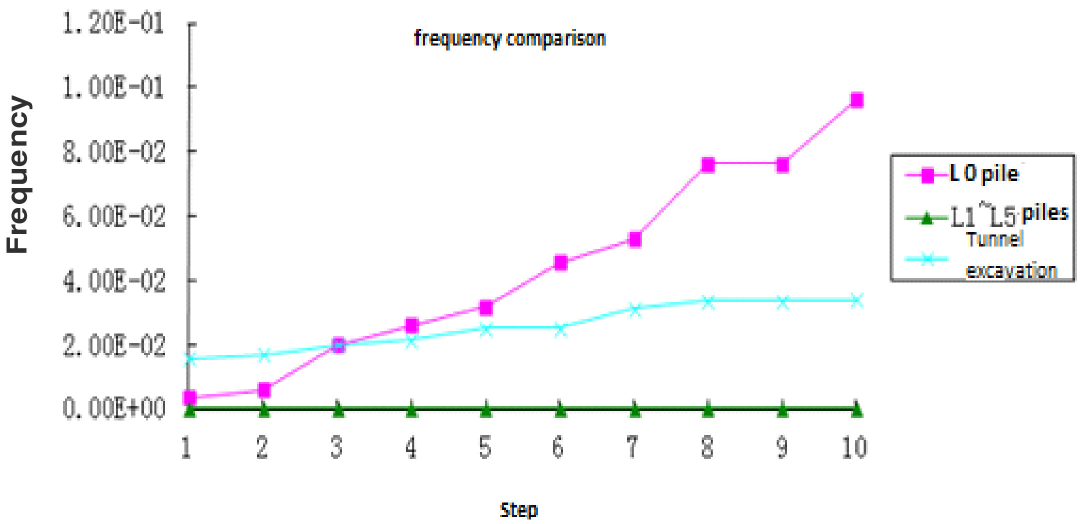

Fig. 10. **Pile of various construction and tunnel excavation vibration frequency**

4. Conclusions

BIM as a parametric design, visualization, and information integration model involves all aspects of the construction industry. Using this model, a full extent of the dynamic simulation has been conducted. If it is within the threshold limits, a gap between the calculated results and the virtual construction have been tolerated. In a situation where excessive deformation was realized in the building process, deformation monitoring and management was strengthened along the tunnels primary support structures erection and construction. In sensitive cases, with the help of real-time BIM technology, immediate feedback was provided during construction and supervision of the viaduct piles, piers and bridges construction. This case study showed that BIM as a product of the current information age opened a new platform for the building science and technology. It promotes optimized time used with a high level of construction precision synchronizing information technology and development. It is the future trend in the construction industry as a bequest from the scientific and technological progress requested by the social development. Along this track, an established continued in-depth technical improvement is required related to the application of technical issues in design and construction.

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