Design and Seismic Prevention of Water Main crossing Faults Cases in Taiwan

Y.S Lai[1]

Y.C. Chou[2], J.L. Lin[2], J.Z. Liao[2], J.J Chen[2]

[1]Region Engineering Office, Taiwan Water Company
[2]CECI Engineering Consultants, Inc., Taiwan.

Abstract

Design of underground pipeline should consider the geology, environment and influence of active fault. Two cases of water mains seismic strategy passing through active faults will be discussed. First is TWC water main project, its alignment is close and almost parallel to the Shan-Yi active fault in Miao-Li. The pipeline will cause severer damage than the situation just cross the fault, such as the Taipei Dadu water main project (alignment is cross Shan-chiao active fault). Meanwhile, the seismic design strategy and analysis is totally different. This paper will demonstrates the TWC project feasible engineering judgments, design with BIM techniques and the shield tunneling consideration in hard gravel formation as reference.

一、Foreword

For water supply in urban area, some pipeline being parallel or crossing active fault should be considered. TWC water main project alignment is parallel with San-Yi active fault, maintenance walkway space is kept within shield tunnel. The main design task is to analyze influence of earthquake waves. Taipei Dadu water main project alignment is cross Shan-chiao active fault, the main design task is to analyze displacement of fault moving. Owing to complicated pipeline layout, these two

cases consider 3-D numerical analysis model instead of conventional plane strain method.

二、Dynamic analysis method of water main tunnel

Influence of earthquake induced by active faults moving can be classified into two types. Type I consider influence of water main structure from fault moving wave, ex. TWC project. TypeII consider influence of water main structure from fault moving displacement, ex. Dadu project.

2.1 Influence of water main structure from fault moving wave analysis

2.1.1 Racking method

Analysis of underground structure such as water main is different from general structure. Racking method is adopted usually, where the racking angle is given to simulate stratum deformation. The racking angle is seldom less than 0.5%, and is related to stratum SPT-N value.

The racking deformation induced by earthquake force within free domain is calculated as follow equation.

$$R = I \times \frac{V_{\max}}{C_{se}}$$

Where I=1.2 is importance coefficient, $V_{\max}$ is largest velocity of ground movement, and Cse is stratum shear velocity, which can be estimated as follow equations if no measured value.

$C_{Se} = 100N^{\frac{1}{3}}$ (Cohesive soil)

$C_{Se} = 80N^{\frac{1}{3}}$ (Cohesionless soil)

The TWC project consider joint between launching shaft and shield tunnel by racking method, where stress concentration occurs as Fig.1a and 1b. To analyze soil structure interaction(SSI) effect, numerical analysis must

involve structure and surrounding soil, which will take more time to calculate.
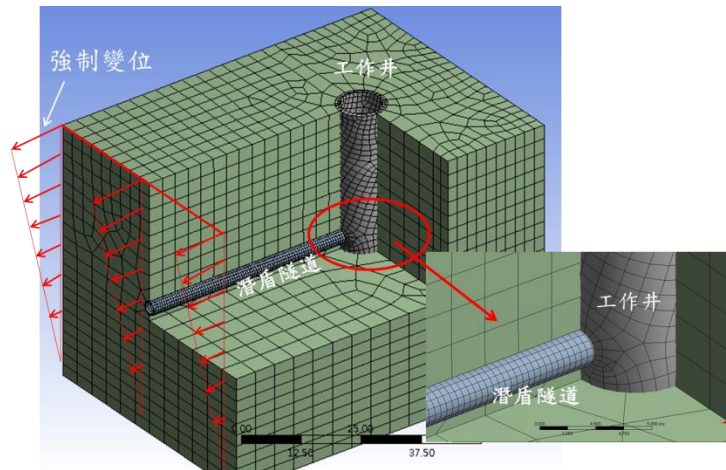

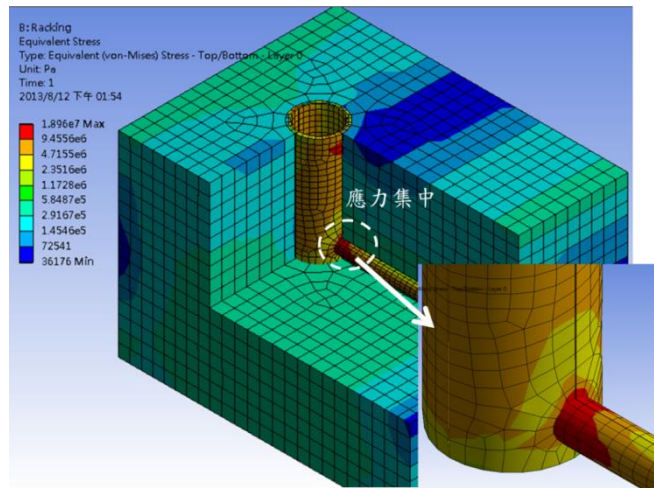Fig.1a Analysis Mesh of launching shaft and shield tunnel

Fig.1b Stress increasing contour of racking method

2.1.2 Response Spectrum Analysis

The TWC project in shield tunnel with maintenance walkway space, which is surrounded by air instead of soil, thus racking method is not available.
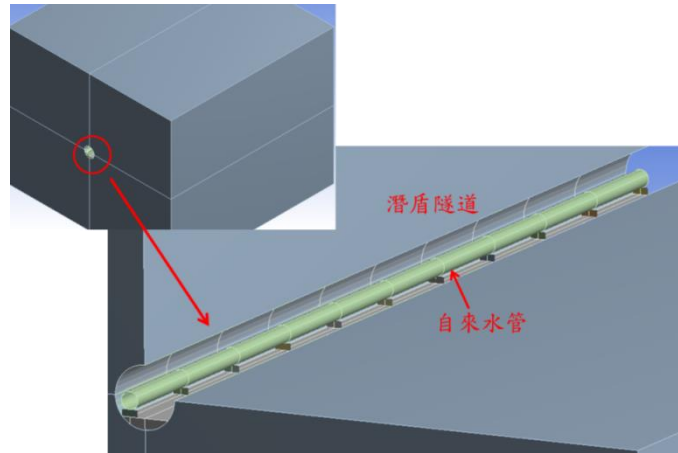
Fig.2 3-D layout of TWC project water main

Response spectrum analysis is more usually adopted than time domain analysis due to calculation time is less, especially for the complicated degrees of freedom.

Usually we take basic mode instead of high frequency mode to simulate dynamic analysis, so 10 modes is progressed of TWC project as Fig3. The 10 modes earthquake response of TWC project can be got after calculation of both modes frequency and acceleration spectrum from NCREE, where the 1st mode(0.73Hz) and 4th mode(1.83Hz) contribute 70% and 16% of earthquake response. Thus the dynamic behavior is composed of 1st mode and 4th mode.
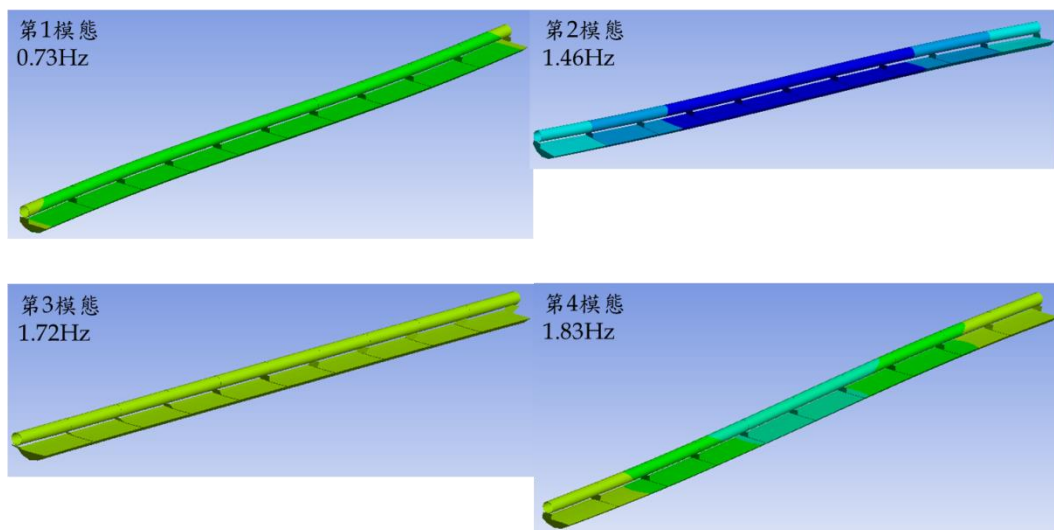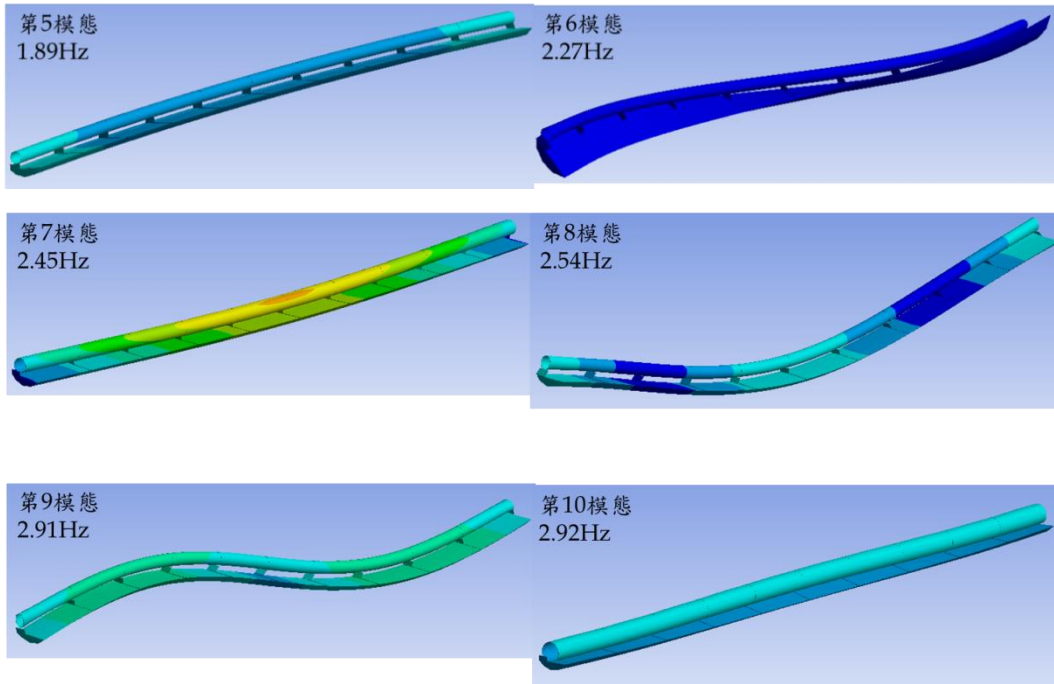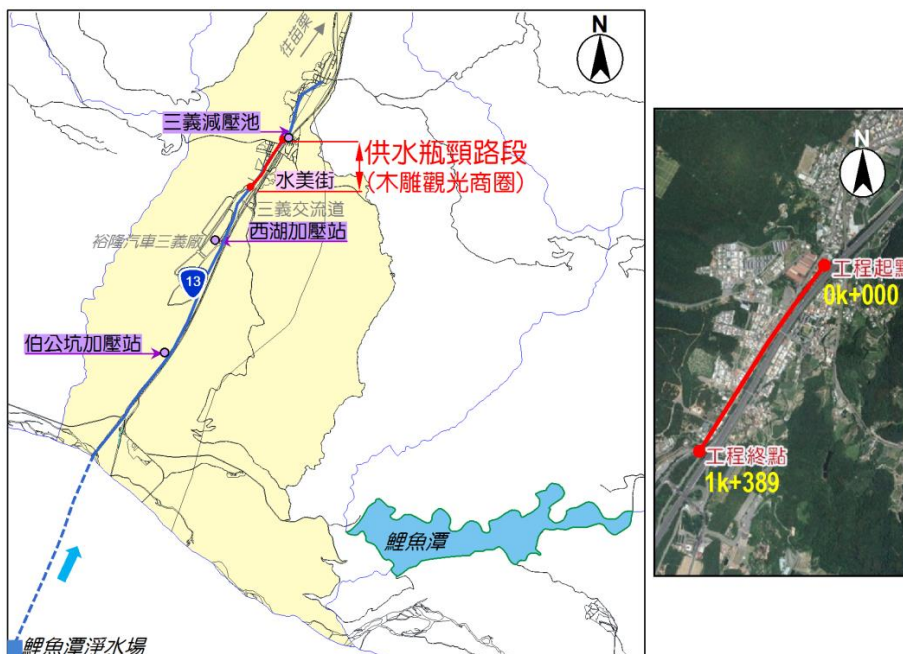
Fig.3 Related frequency of 10 modes frequency of TWC project

三、**Introduction of TWC water main project**

The TWC project locates on Sanyi Township, Miaoli County. Where φ 1000mm water main is 1416 meters long within shield tunnel, and connected with φ 1000mm pipe lines at both ends to supply water for neighbourhood area. The project location is shown of Fig.5

Fig.5 Location of TWC project

3.1 Location

The TWC project is located under No.13 provincial road within a tourist spots, as shown of Fig.6.

❶ 0k+000 路線起點

❷ 0k+200 水美街

❸ 0k+500 水美街

❹ 0k+700 自來水設施

❺ 0k+950 水美街

❻ 1k+200 水美街

❼ 1k+300 水美街

❽ 1k+416 路線終點

Fig.6 Photos of TWC project

3.2 Topography, Geology and Groundwater

3.2.1 Topography and Geology

The site elevation is 310~365 meters at hill area with gravel formation, where gravel diameter is 0.2~1.0 meters.

The geological structures at site neighborhood are syncline and San-Yi

active fault. Where San-Yi active fault locates 170~230 meters from site with apparent influence of TWC project. The site geological map is shown as Fig.7
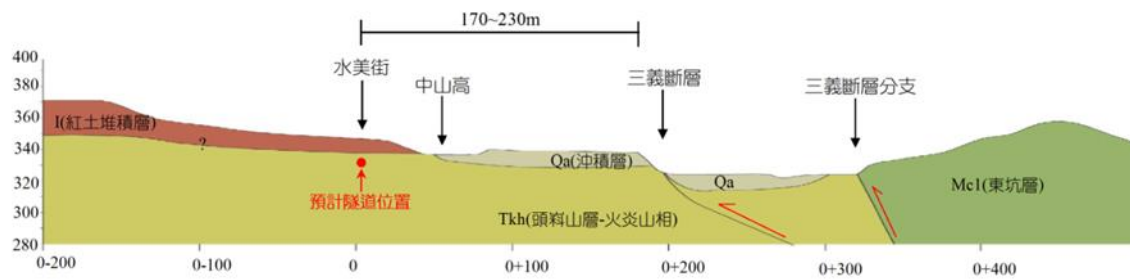

Fig.7 Geological map and profile of TWC project

3.2.2 Groundwater

Most of the project alignment is above groundwater level after boring observation as shown of Fig.8. Groundwater level near launching shaft is about -5.7~-12.6 meters, and about -40.0m of arrival shaft.
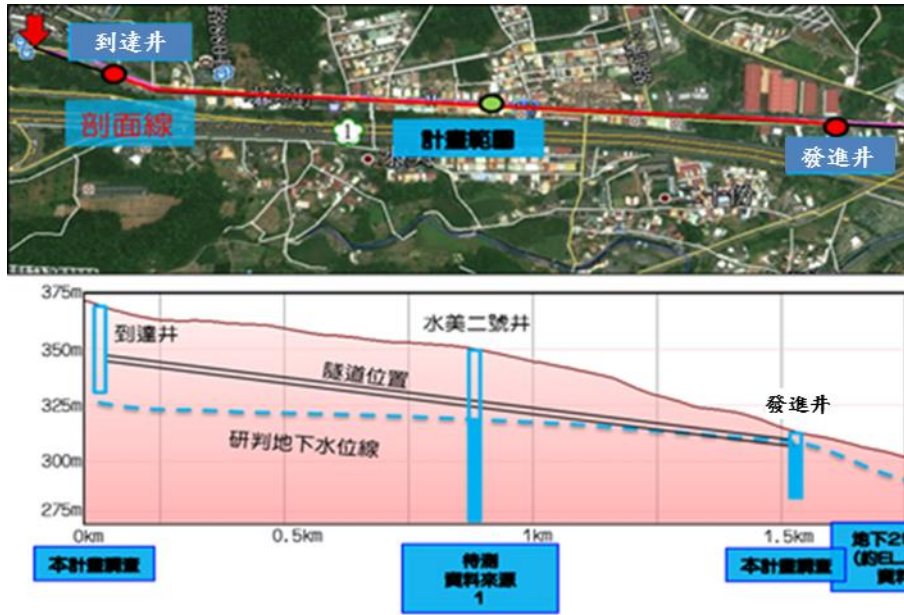
Fig.8 Groundwater condition

3.2.3 Engineer Geology

The site formation include overlay, sandy silt and gravel. The gravel uniaxial compression strength is between 735~1475 kgf/cm2. The simplified stratum parameters is shown as Table 1.

Table 1 Simplified stratum parameters

layer	Stratum	Depth (m)	SPT-N value	γ_t (t/m^3)	c (t/m^2)	ϕ (deg.)
1	Overlay	1.2	-	1.80	0	29
2	Sandy silt	3.2	9	1.91	0	31
3	Gravel	40	50	2.10	0	35

3.3 Shield Tunnel Design

3.3.1 Tunnel alignment

The TWC project should consider shield tunnel construction and pipe installation. Especially the tunnel overburden depth, alignment slope and smallest drainage slope in tunnel.

3.3.2 Tunnel profile

1. The φ 1000mm water main must consider maintenance walkway and pipe reinstallation space.

2. The ventilation of restricted space must be considered for maintenance safety.

3. The tunnel inner diameter is 3200mm, and segment thickness is 200mm. Where the profile is shown as Fig.9
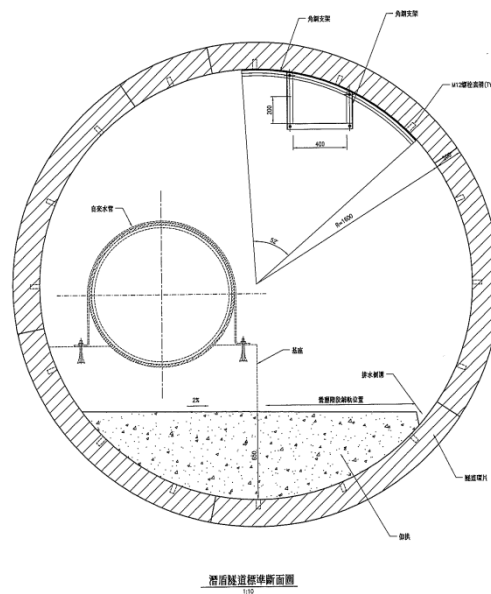

Fig.9 Tunnel profile

3.3.3 Segment Design

The tunnel segments are composed of three type A, one type B2, one type B1 and one type K (longitudinal installation) parts. The segment width is 1.0m, and thickness is 200mm.

3.4 Launching and Arriving shaft

1. The shaft diameter is 8 to 10 meters for shield construction and pipe installation needs.

2. Launching shaft caisson depth is 12 meters with press-in assistant method. The layout is shown as Fig.10 and Fig.11.

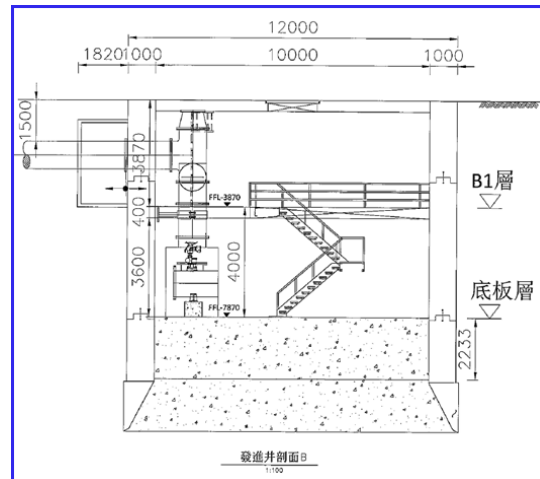Fig.10 Location of Launching shaft   Fig.11 A-A profile of launching shaft

3. Arrival shaft depth is 29 meters, which is constructed by Liner plate method. The layout is shown as Fig.12 and Fig.13.
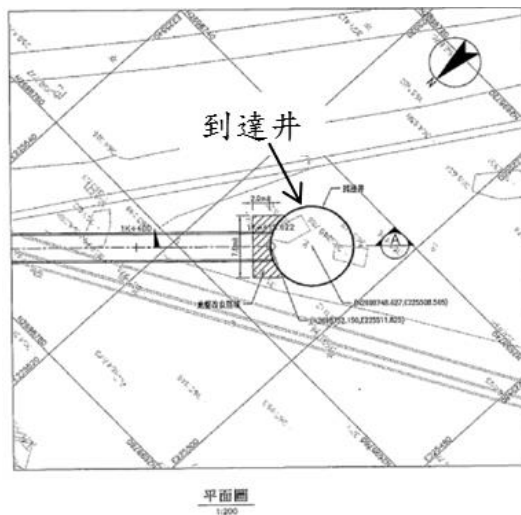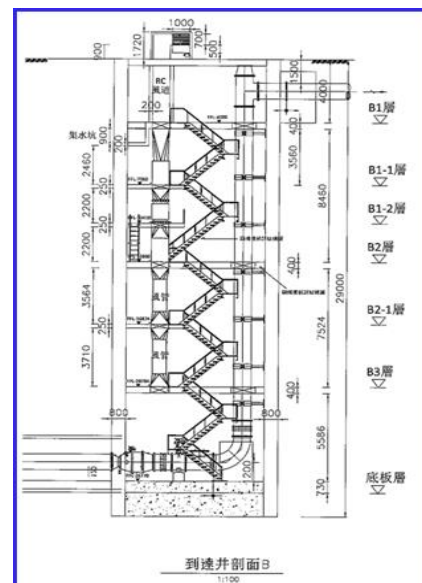

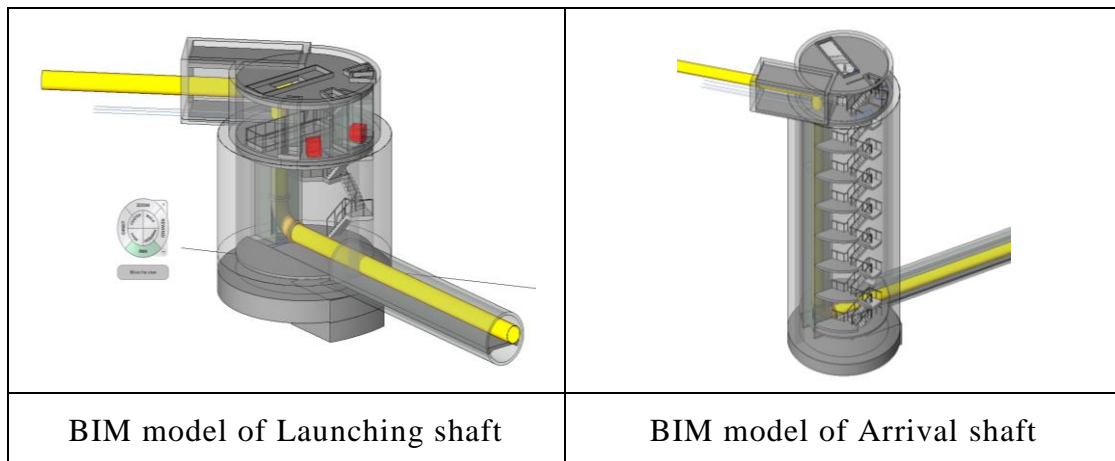Fig.12 Location of Arrival shaft   Fig.13 A-A profile of Arrival shaft

3.6 BIM Appalication

Building Information Modeling (BIM) is used to confirm the maintenance space of tunnel and shafts, which can be as reference of construction and maintenance period for life cycle.

BIM model of Launching shaft	BIM model of Arrival shaft

3.7 Construction of Gravel Formation

The main tasks of shield progress in gravel formation includes gravel hardness (highest qu is 2000kgf/cm2), cutter wear from matrix blocking, low progress rate, shield shale deformation induced by gravel compression…etc. Consider the TWC project alignment is above groundwater level, semi-mechanical open type shield is adopted for benefits of cutter wear, progress rate and more economic.

四、conclusion

1. The water main design of crossing fault condition should consider both earthquake wave and fault moving tasks.

2. Composite analysis of both soil and pipeline is suggested to avoid soil and structure interaction (SSI).

3. Shield tunnel with maintenance walkway space should consider ventilation for safety.

4. BIM is available for design, construction and maintenance.