Various use of diaphragm walls for construction of multilevel road junction – Design and monitoring of displacements

Diverses utilisations de parois moulées pour la construction de l'intersection des routes à plusieurs niveaux – Conception et le suivi des déplacements

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ABSTRACT: The paper presents various use of diaphragm walls for the construction of four-level junction in Warsaw. Diaphragm walls were chosen as a best solution for abutments of 2 viaducts and 1 flyover, foundations (barrettes) under 7 pillars, 60 to 100cm thick retaining walls with total length of over 570 running meters. In the paper detailed technical descriptions, geotechnical conditions, predicted theoretical horizontal and vertical displacements of walls for all mentioned diaphragm wall applications are presented. Finally, the comparison of the results of theoretical analysis and real scale monitoring results (displacements measurements and load tests) in accordance with construction stages is presented and discussed.

RÉSUMÉ : Cet article présente différentes utilisations de parois moulées pour la construction d'une jonction de quatre niveaux à Varsovie. Les parois moulées ont été choisies comme une meilleure solution pour les butées de 2 viaducs et 1 voie surélevée, les fondations (barrettes) sous 7 piliers, des murs de soutènement épais de 60 à 100 cm avec une longueur totale de plus de 570 mètres. Dans le document des descriptions techniques détaillées, des conditions géotechniques, les prévisions de déplacements horizontaux et verticaux théoriques des murs pour toutes les applications de parois moulées mentionnées sont présentés. Enfin, la comparaison des résultats de l'analyse théorique et les résultats en vraie grandeur (mesures de déplacements et de tests de charge) de la surveillance conformément aux étapes de la construction est présentée et discutée.

KEYWORDS: diaphragm wall, deep excavation, foundation, barettes

1 INTRODUCTION

In Poland nowadays, especially before euro 2012, road network and new motorways connecting Poland and Ukraine with Western Europe are being built. Construction of Warsaw bypass is the place were huge multilevel road junctions are built.

The case disscussed in the paper is 3 level road junction consisting of 2 flyovers (indicated as E1, E2 at fig. 1) and 2 viaducts (indicated as W1, W2 at fig. 1). The original building permit design assumed that the abutments and columns were to be founded on large-diameter piles with the diameter 120 and 150 cm. The accompanying RC retaining walls and viaduct abutments were to be erected in traditional formwork. The original design assumed that the embedded part of the junction was to be built with a temporary casing in the form of sheet piling with an RC capping beam at the top. The walls were to be anchored with 1 level of soil nails. Permanent structure was designed as retaining walls connected with water tight foundation plate. During the execution design stage,
due to economical and technological reasons, the solution was much simplified - only diaphragm walls were used for all parts of the structure, i.e. for:

- excavation walls – retaining structures,
- foundations – barrettes of viaduct columns as well as barrettes of columns and abutments of flyovers,
- viaduct abutments – T-shaped diaphragm walls.

The new solution allowed the significant shortening of construction works through the use of diaphragm walls as temporary and permanent structure. Figure 1 presents the general arrangement of the discussed road junction and indicates parts of the structure described in the paper.

In the design stage theoretical displacements and bearing capacities of theses structures were calculated. During construction, at each of disscussed structure parts, the real

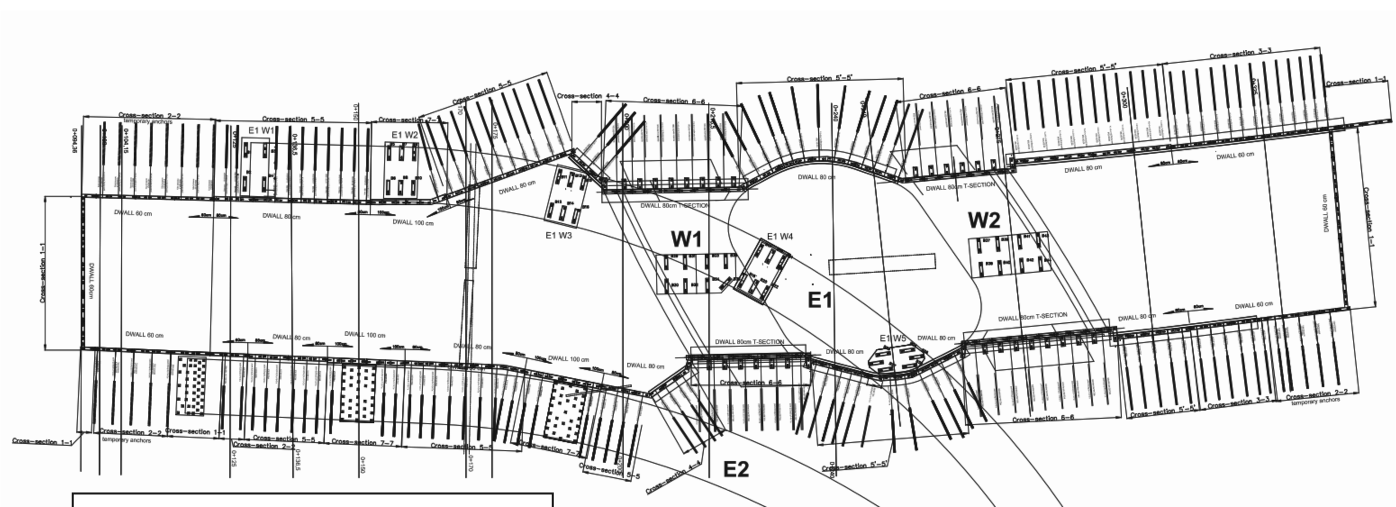

Fig. 1 General arrangement

horizontal displacements and settlements were measured and compared to theoretical values calculated in the design stage. It has allowed an assessment of the correctness of the solution.

2 GEOTECHNICAL AND HYDROLOGICAL CONDITIONS

The ground in the land plot consists mainly of Quaternary formations: river sediments and glaciofluvial deposits as well as glacial deposits. In the entire area involved in the investment, the near-surface layers below man-made fills consist of medium-dense and dense sands and gravels reaching down to the max. depth of 18.8 m. Below (the layer roof from 10.6 to - 18.8 m), there are glacial clays, deposited in the form of stiff sandy clays, clayey sands and, locally, silty clays. The layer of anthropogenic soils is not very thick: maximum thickness: 2.2m, average thickness: about 0.5-1.00 m.

Within the entire area, a continuous ground water table was found in the layer of glaciofluvial sands. The ground water table was located at about -4.5 m below the ground level. Occasionally, the water table was confined by lenses of cohesive soils.

3 DIAPHRAGM WALLS AS A RETAINING WALL

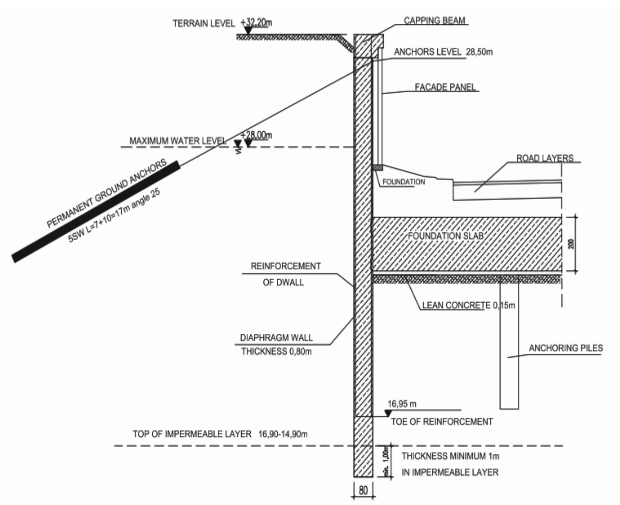

Fig. 2 Typical cross-section of the excavation wall; 80cm thick diaphragm walls, anchored using permanent anchors.

Due to variable embedding of the excavation below the ground level, down to the maximum depth of 10 m below the ground level, diaphragm walls with 3 different thickness values were implemented, namely 60 cm, 80 cm and 100 cm. Moreover, different types of protective measures were implemented to ensure stability of casing walls, i.e:

- temporary ground anchors, 600 kN capacity (cross – section 2-2),
- permanent ground anchors, 600 - 700 kN capacity (cross-sections 3-3, 4-4, 5-5),
- permanent ground anchors in the area of T-shaped D-walls, 700 kN capacity (cross section 6-6).

Some parts of walls reamined not supported (cantilever walls) due to the small hight of excavation (cross-section 1-1) or possible colisions with pile foundations outside the wall (cross-section 7-7).

In total 148 ground anchors were executed (18 temporary and 130 permanent) and 31 permanent ground anchors for abutments.

Diaphragm walls along the entire perimeter of the facility (including the transversal walls) were embedded at least 1 m down into the impermeable layer, in order to minimise the inflow of water into the excavation (fig 2). Due to unbalanced hydrostatic pressure, the ground slab was anchored with displacement piles in its central part in the deepest excavation (fig 2.).

Diaphragm walls were designed to resist loads resulting from soil pressures and from service loads at the ground surface generated by vehicles and stored materials, amounting to q=12,0 kPa in the zone removed by at least 1.5 m from the wall face, and loads generated by heavy traffic, amounting to q=30 kPa. Additionally, the design considered a load generated with vehicle K located on the roadway located in close vicinity of the diaphragm wall, in compliance with standard PN-85/S-10030 Bridges. Loads.

Static analysis of diaphragm walls were made using dependent pressures method (PAROI). 7 typical calculation cross-sections were verified. Typical results of calculations – bending moments and displacements – are shown at fig. 3. Maximum theoretical values of horizontal wall displacements are as follows:

- cantilever D-wall - 6 mm;
- D-wall and temporary ground anchors - 15 mm;
- D-wall and permanent ground anchors - 12mm;
- T-shaped D-walls - 8mm.

Corresponding bending moments amount to 180 kNm/m up to 700 kNm/m.

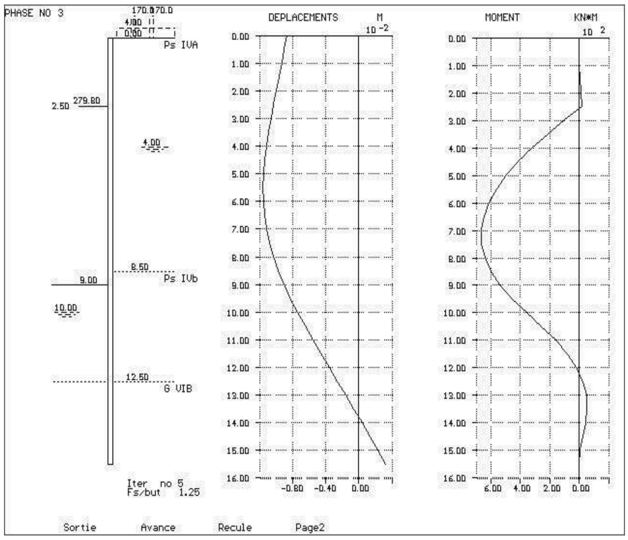

Fig. 3 Theoretical values of bending moments and horizontal displacements for 80cm thick D-wall with permanent ground anchors (corss-section 5-5) in the final construction stage.

Benchmarks for geodesic measurements were located on the capping beam of diaphragm walls, spaced every 50 m at the maximum. Measurements were carried out for particular stages of execution of works on site, at least once every month or more frequently.

Construction stages were as follows:

- site preparation, sub-base preparation, construction of guide walls and D-walls with RC capping beam – reference measurement,
- excavation 0,5m below the anchoring level – measurement 1,
- execution and stressing of ground anchors – measurement 2,
- final excavation – measurement 3,
- verification of displacemants during the execution of driven piles – subsequent measurements.

Particular attention was paid to measurements of wall displacements in the vicinity of works consisting in driving displacement piles in, in order to anchor the ground slab. In the view of the presence of a layer of silty sands, designers were concerned about the impact of dynamic pile driving on the load-carrying capacity of ground anchors, whose bearing plates are embedded in these sands. The monitoring of displacements of the capping beams of diaphragm walls showed that their maximum value reached 10 mm for an 80 cm thick wall, anchored with permanent anchors. In the case of other cross-sections, displacements were smaller and reached up to 8 mm. No increased displacements of the diaphragm wall were observed during the process of pile driving.

Design works had to face additional difficulties resulting from the very complex shape of the facility, involving 4 abutments (T-shaped D-walls, cross-section 6-6) and curved walls that encased the roundabout (cross–section 5'-5'). Both the excavation bottom and the top of the walls and the capping beam were located in slopes. Due to this fact combined with variable thickness and varied strut methods, almost every single reinforcing cage of a diaphragm wall was of different type. Therefore, the contractor who constructed diaphragm walls was forced to stick strictly to the schedule of execution of particular sections, without any possibility of introducing changes during the works.

4 DIAPHRAGM WALLS AS FOUNDATIONS FOR PILLARS AND COLUMNS

A foundation on barrettes (parts of diaphragm walls) – instead of large-diameter piles (∅ 120/150) implemented in the construction design – was designed for 5 supports of the flyover E1 (4 pillars and 1 abutment) and viaducts pillars – viaducts: W1 and W2 (fig.1). The barrettes – as fragments of diaphragm walls – have a very large base. Therefore, they can transmit very high loads. For this reason, they are very useful for structures subjected to very high loads, as in this particular case of bridge structures.

The replacement, for instance, of the support consisting of 11 piles that were 150 cm in diameter with 6 barrettes resulted in a considerable acceleration of works, which brought about a measurable financial result in this particular case. Typical arrangement of the pillar foundation is shown at fig. 4.

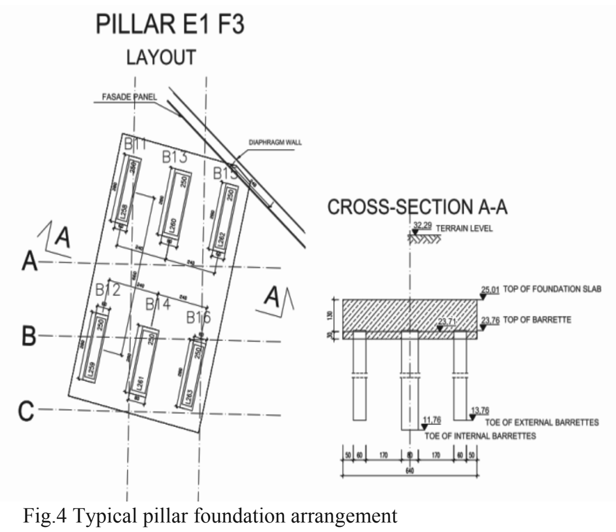

Fig.4 Typical pillar foundation arrangement

Barrettes implemented as foundations for pillars had the following dimensions: 0.6x2.80 m and 0.8x2.8m. They were from 10.0 to 15.0 m long. They transmitted vertical forces reaching the max. value of 7600 kN and the bending moment reaching the max. value of 4996 kNm. In total 44 barrettes were erected.

Internal forces and moments for each barrette were calculated using ROBOT software, modelling supports loaded by a possible most unfavourable load combination. Due to unsymetrical loading of supports each barrette had different loading (both - compression as well as tension) and different bending moments in both directions.

For each of barrettes additional boreholes were made in order to verify geotechnical conditions. Only then the design of lengths and calculation of bearing capacities of barrettes were made. It was considered that barrettes were founded in the stiff sandy clay layer and the shaft friction was calculated considering 2 geotechnical layers along barrettes, i.e. stiff sandy clays and medium dense to dense fine and silty sands.

Base bearing capacities and shaft fricitons were calculated basing on the regulations of PN-83-B-02482 Foundations. Bearing capacity of piles and piles foundations.

A base injection system was designed for all barrettes, in order to ensure as high load-carrying capacity of a barrette as possible, while ensuring minimum settlements. In each support, one barrette was selected to be subjected test vertical loads, supposed to confirm the adapted geotechnical parameters were correct. The results of test loading showed that the load-carrying capacity of barrettes was higher than necessary, while the settlements were smaller than admissible.

Vertical loading tests of barrettes was carried out for 6 barrettes that were gradually loaded up to the maximum of 150% of the calculation force. After reaching 100% of design load the barrettes were unloaded in order to measure the resulting permanent settlement. Analogical procedure was used after reachning 150% calculation force. Permanent settlements at the 150% force (i.e. 5286 - 10397 kN) did not exceed 4 mm, while they reached 2 mm for 100% of the calculation force (i.e. 3524 - 6931 kN). The barrette (dimensions: 0.6x2.8m, length: 13.1m) subjected to the greatest load experienced maximum settlement of 4.35 mm at the load of 10397 kN, where permanent settlement reached 2.91 mm. The results of settlement measurements during test loading of barrettes are compiled in table 1.

Table 1. The results of vertical loading tests of barrettes – settlements.

No.	*Dimensions*	*Settlements for 100%Q*		*Settlements for 150%Q*	
		temporary	*permanent*	*temporary*	*permanent*
B8	2,8x0,8 x10,0m	6001 kN		9002 kN	
		3,96mm	1,61mm	7,54 mm	3,53 mm
B12	2,8x0,6 x10,0m	3524 kN		5286 kN	
		1,33mm	0,75mm	2,82mm	1,71mm
B18	2,8x0,6 x10,0m	5889 kN		8834 kN	
		2,36mm	1,32mm	4,56mm	2,69mm
B31	2,8x0,6 x12,0m	5989 kN		8984 kN	
		2,53mm	1,32mm	5,29mm	3,09mm
B24	2,8x0,6 x13,1m	6931 kN		10397 kN	
		1,99mm	1,08mm	4,35mm	2,91mm
B41	2,8x0,6 x14,0m	4594 kN		6891 kN	
		1,80mm	1,14mm	4,17mm	2,84mm

As a part of interpretation of the test loading results auxiliary graphs were ploted as shown at fig. 5, in order to help calculate the bearing capacity of barrettes.

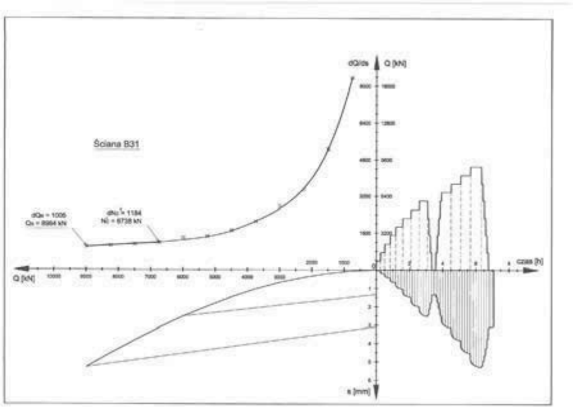

Fig. 5 Static load test result

5 DIAPHRAGM WALLS AS VIADUCT ABUTMENTS

The contour of the casing of the lowest level of the junction contained 4 viaduct abutments (viaduct W1 and W2). They were designed as 80 cm thick T-shaped diaphragm walls. Additional limitations were imposed for these fragments of diaphragm walls with respect to both horizontal and vertical displacements, caused by the selection of appropriate bearings. Additional permanent anchors were implemented – fig. 6, in order to minimize horizontal displacements of walls. In total, in the area of viaduct abutments, 31 permanent ground anchors of the 700kN capacity, were erected.

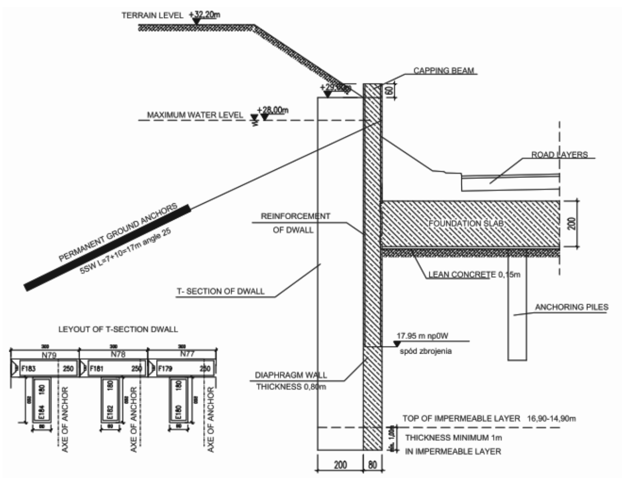

Fig. 6 Typical T-shaped D-wall cross-section for the W2 viaduct abutment.

Due to the fact that abutments were founded in the same stiff sandy clay layer as remaining barrettes made for the foundations of pillars, additional, special loading tests were not carried out for the T-shaped diaphragm walls. Bearing capacities of T-shaped barrettes were calculated by interpolation of the results of tests loadings of individual barrettes executed in the near vicinity of abutments. Additional limitations were imposed for T-shaped diaphragm walls with respect to horizontal displacements. In order to comply with limitations and minimize horizontal displacements of walls additional permanent anchors were implemented. The design load of permanent anchors was verified during acceptance tests. Each anchor was stressed up to 125% of its design load and after stabilization of creeping it was blocked at 80% of its design load. There were no excess permanent or elastic strains of anchor tendoms measured, in accordance with regulations of the code: PN-EN 1537 Execution of special geotechnical works. Ground anchors.

6 SUMMARY AND CONCLUSIONS

The results of diapragm walls (as retaining walls) horizontal displacements measurements confirmed the correctness of static analysis of walls and prediction of their displacements, both made during design stage. Maximum value of horizontal displacement reached 10 mm for an 80 cm thick wall, anchored with permanent anchors and it didn't exceed neither theoretical nor permissible values. In the case of all other cross-sections, displacements were smaller and reached up only to 8 mm.

The results of vertical loading tests made for the barrettes confirmed the value of calculated theoretical bearing capacity being 7600 kN to be correct.

There were no significant horizontal displacements of T-shaped diphragm walls noted (measured).

The new solution applied in the execution design (replacing the original one from the building permit design) was correct and resulted in significant savings due to the use of only one technology for the foundation and the retaining system (diaphragm walls) of the entire 3 level road junction construction. Most of the savings were obtained as a result of significant shortening of construction works.

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