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The influence of vibrations on Ateneum

L'influence des vibrations à Aténeum

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SYNOPSIS Driving of piles close to a building once placed upon wood piles, later underpinned by megapiles, without damaging the already affected frame is a task where calculations must be supported by tests. The proposed slim circular ductile iron piles and the tests described in this paper proved that the vibrations and settlements can be kept within allowable limits. Through a large monitoring some interesting phenomena concerning the acting of the megapiles and the distribution of the vibrations could be observed.

Renovation of Ateneum

The building of Ateneum is located in the heart of Helsinki. The wood piling was done in the years 1885-1887. The base of the building was 3000 m² the volume 48.000 m³. It consists of cellar, 3 floors and ceiling. In 1900 it was enlarged for the first time. The whole building was underpinned by megapiles in 1968. From the beginning the Ateneum has been the seat of art, museum, Finnish Academy of Art aso. Through this renovation the cellar and ceilings will be utilized as well as the space below the yards. The old cellars are made deeper to the same level as the new ones, 0.4...0.7 m below the waterlevel. Due to difficult conditions and type of foundations the project is geotechnically requiring and interesting. The renovation will be performed during three years under the supervision of the National Board of Public Building. Planning and realization is done by private consultants and contractors.

Ground conditions and foundations

The building is situated on the area of the former Kluuvi Bay, filled in 19th century. The ground level is now at +2.0. The bedrock is at a depth of 20 meters, and it is overlaid by a relatively dense glacial till, consisting of silt, sand and gravel. The clay layer above is separated from a silty loam by a thin uniform beach sand. The fill has a thickness of up to 5 meters and it is built up mainly of silt, sand, stones and boulders. The fill has partially plunged into the loam. The upper groundwater level above the clay is around +0, but the real or lower one is around -1.0. In the neighbourhood are several buildings on wood piles. Originally Ateneum was on wood piles driven to refusal in the dense layer of till. Upon the piles was built a mattress of timber and



Fig.1 Ateneum

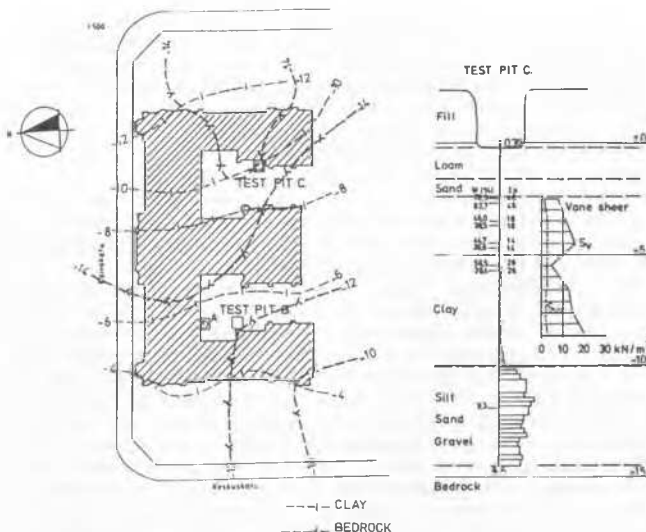


Fig.2 Soil conditions

the stone walls. In 1968 the building was underpinned with megapiles as the wood foundations were damaging and differential settlements with accompanying cracks occurred. The piles were driven with hydraulic jacks through the clay and stopped when they reached the silt, sand and gravel. See picture 3.

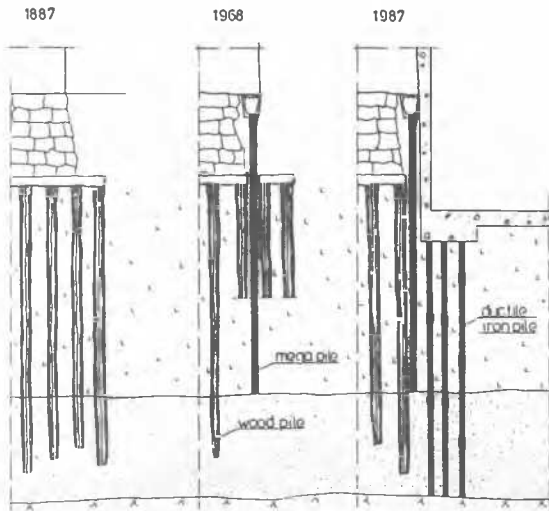


Fig.3 Evaluation of piles

THE BASIC ASPECTS FOR THE PLANNING

The effects of dynamic loadings from foundation engineering works

Referring to the ground conditions, the type of the existing foundations and the state of the frame it was obvious that the building is very sensitive to dynamic loadings. The influence of the traffic was earlier measured and reached values of ≤ 1.0 mm/s in vertical direction. Different piling methods were studied regarding costs v. vibrations. Especially the piling to be made in the existing cellars with limited height had a great influence in the choice. The underpinning made in 1968 was naturally a vibrationless method but nowadays it is very costly and not very suitable for newbuilding. Experiences from representative piling jobs were collected. Some years ago precast, in-situ and bored piles were used closed to a building underpinned by megapiles. Although only settlements (10...20 mm) were measured it brought a clear picture of how sensible a construction of this type is. Recently some more detailed studies and comparisons of the effects of driven piles of different sizes, had been carried out. I.e. a 300×300 mm² concrete pile caused in clay formations twice as much vibrations as a $\varnothing 170$ mm ductile iron pile, although they were driven with the same drop weight. In another project the use of slim profiles combined with light pneumatic

hammers gave very small vibrations. Much less facts about the vibrations caused by the breakdown of structures were to be found. Is this a forgotten topic? The only field where vibrations are plentifully measured is that of blasting of rock. But the range of the frequencies are roughly about ten times greater than those of piling so the experiences are not directly valid. All together too little sources could be found to make a theoretical realistic study of the problems at Ateneum. The owner agreed upon a test piling and with future projects in mind asked for a serious study of as well the test as the final execution.

TEST PILING

General

The goal for the test piling was to check the degree of vibrations when using slim steel piles driven by a light hammer and the influence of the vibrations on the building, megapiles and ground. The correlation of size of the pile, distance, number of blows and penetration of the ground was to be studied. Also the bearing capacity of the piles and driving instructions for the final piling should be fixed. There were three test pits chosen so that the adjacent structural shape was each time of a different type as corner, long wall and braced wall. The fill was removed so the piling started directly into the natural soft layers of loam and clay.

Piles and equipment

The test piling consisted of six Gustavsberg ductile iron piles. Two piles had a diameter of 118 mm and a wall thickness of 8.4 mm and the rest respectively 170 mm and 11 mm. The piles were delivered in pieces of 5 m and coupled with rigid conical sleeves. See picture 4. The smaller weighed 26 kg/m and the larger 48 kg/m. The piles were equipped with flat shoes. As hammer was used an Atlas Copco pneumatic hammer PH 180. The total weight was 880 kg and the piston 112 kg. Nominal speed was 330 strokes/min with an airpressure of 600 kPa. The guidance of the hammer was very primitive, which allowed horizontal deflections and uncentered strokes. The piles were placed 1...2 meters from the building and the distance to the megapiles varied from 1.35 meters to 2.1 meters.

INSTRUMENTATION

Vibrations

The velocity and acceleration were measured with 13 vertical geophones and 6 horizontal ones. 2 geophones were fixed to the ductile iron pile to be driven, 2 to the cut-off

megapile and 2 to the adjacent megapile. The rest of the geophones were spread out in the building and the fill. For comparison some geophones were moved from first floor to second floor when driving the second pile of the test pits. The results were registered on UV-plotters.

Settlements

Eventual vertical movements were checked in 22 points through accurate levelling points and all significant existing cracks were registered and monitored by small "bridges" of gypsum. One megapile per test pit was exposed and cut off and furnished with a dial indicator. A hydraulic jack was installed to keep the cut megapile under a constant load of 400 kN during the piling or as in some cases without load. See picture 4.

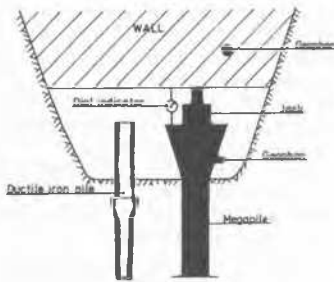


Fig.4 Test pit

Pile Driving Analysis

All piles were measured during the whole driving process with a PDA-instrument. The results were registered on a tape for further detailed studies. See picture 5.

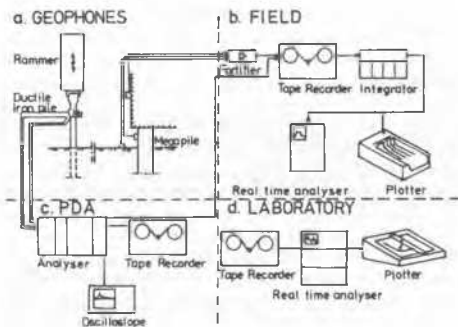


Fig.5 Instrumentation

MEASUREMENTS

Vibrations

The velocities and frequencies were registered in correlation to the applied force on the pile cap and the depth of the pile toe. In those points where the velocity vectors were measured in three directions they were transformed to a resultant.

Building

The highest value for the resultant was 1.6 mm/s measured in a column on the first floor when driving a 170 mm pile at a distance of 1.05 m. The pile point was at a depth of 6.5 meters just reaching the sand layers. The corresponding force of the hammer was 550 kN. The horizontal velocity was as high as 1.2 mm/s due to the weak guidance of the piling equipment. All the other calculated resultants in the building stayed clearly below 1 mm/s. See diagram 6.

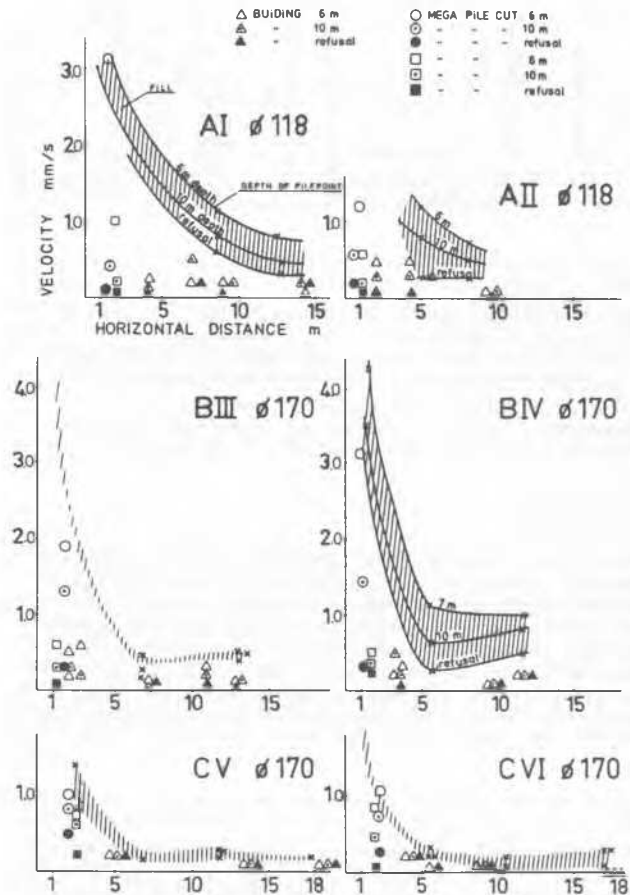


Fig.6 Vibrations

Megapiles

The highest values in the cut and jacked megapile were vertically 3.4 mm/s when the ø 170 mm pile reached the sandlayer with an applied force of 590 kN. There was no significant change in the vibrations of the megapile when it was unloaded. The vertical vibrations of the uncut pile were always less than 1.0 mm/s. The horizontal velocity reached a peak of 5.8 mm/s. Due to the weak guidance the horizontal values did not show any correlations to earthlayers and resistance. When the stroke was well-centered the horizontal values were much less than the vertical ones. The vibrations in

the megapiles decreased with an increasing depth when the pile point had passed the megapiles and reached their minimum when the pile driving came to refusal. See diagram 7.

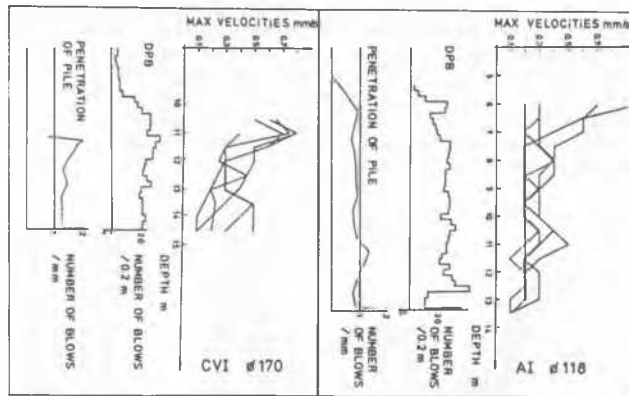


Fig.7 Vibrations, blows and DPB

Fill

Again the bad guidance caused peak values of 11.3...11.5 mm/s vertically measured 1.0...1.5 m from the piles. At a distance of 6 meters the corresponding value was only 0.5...0.8 mm/s. In general the values measured close to the piles when the hammer struck correctly were about 2...3 mm/s.

Settlements

The dial indicators attached to the megapiles showed values of 0...0.02 mm in those piles where the load was kept constant at 400 kN. In the two piles where the load was released during a part of the driving the settlements were 0.15 mm and 0.24 mm. No cracks were noticed in the gypsum bridges and the final accurate levelling control of the building is yet to be done.

PDA

With the CASE-calculation and a J-factor of 0.1...0.2 the ultimate bearing capacity of the \varnothing 118 pile is 390...400 kN and the \varnothing 170 pile 800...840 kN. The corresponding penetration was 0...1 mm/min respectively 0...2 mm/min. As the soft clay layer with a reduced cu-strength will allow with respect of buckling a load of 280 kN respectively 500 kN, it is obvious that the pile must be tested with a larger hammer or a drop weight when it has come to refusal.

CONCLUSIONS

Vibrations

With a strict guidance of the hammer the values of velocity will stay below 1 mm/s in the building. As this is less than the continuous stress caused by the traffic it

can be allowed. The slight difference in the diameters had no significant influence as long as the hammer is the same.

The larger piles should thus be driven with an undersized hammer when passing the sandlayers into which the megapiles are supported. For the final ultimate bearing capacity a more effective hammer should be used. The frequencies where the maximum velocities occurred were 5...20 Hz. The self frequency of the structural parts are in this range which results in a slight increase of the horizontal vibrations in the upper floors but staying still below 1 mm/s.

Some phenomena observed from the test results:

- The vibrations decreased considerably when the piles came to refusal.
- The vertical vibrations in the building and the fill decreased normally in relation to distance when driving \varnothing 118 mm piles, but when driving the \varnothing 170 mm the values increased at a distance greater than the depth to the sandlayer (due to superimposition of R-, P- and S-waves).
- The point of the megapile was the most sensible conductor of vibrations.
- The megapiles when rigid fixed were damped by the mass of the building.
- No noticeable change of vibration in the megapile when it was unloaded.
- The factor of transfer from ground to building was 0.25...0.30 at a distance of 2 meters from the pile.

Settlements

As the test piling caused none or minor settlements in the adjacent megapiles it is obvious that the final piling due to its great number of piles can be predicted to reach values of 1...4 mm. But as the new piles are evenly spread there will be no abrupt differential settlements.

Piling equipment

A well guided piling device with a centered stroke and if necessary a reduced air pressure when passing the critical layers will keep the vibrations and settlements at a minimum. The number of blows for the smaller pile was about 9.400 and for the larger about 14.700. Some of the larger piles should be tested with a heavier hammer or testloaded in order to get a maximum load.

Piles

The slim profiles and round shape proved to be suitable for penetrating the layers and reach the hard strata with a light equipment. The pile has a favourable circular shape against buckling. As the smaller pile is manufactured in pieces down to 1 meters it is very suitable for indoor works. Due to the hollow section they can always be inspected for integrity and deflection thus keeping the safety factor at a reasonable level.