ORIGIN OF GEOTECHNICAL DISPUTES AND THEIR RESOLUTION

ORIGINE DE CONTROVERSES GEOTECHNIQUES ET LEUR RESOLUTION

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SYNOPSIS: The purpose of this paper is to highlight some of the most frequent causes of disputes due to geotechnical problems appearing in structural engineering Examples of disputes, experienced by the Author, and their origin and resolution are presented. Dispute resolution mechanisms are discussed. Main subjects for discussion are proposed.

INTRODUCTION

The professional practice in geotechnical engineering and the degree of liability of the geotechnician, if something goes wrong, varies from country to country. In some countries, the legal responsability of design, even with regard to choice of foundation system, retaining structures and so forth, rests completely on the structural engineer, while in other countries the legal responsability of geotechnical design rests completely on the geotechnician himself. In the former case, since he is not a geotechnical expert himself, the structural engineer is apt to choose safe, conventional solutions to the foundation problems. The latter state of things is doubtless preferable as it may encourage to more advanced and unconventional geotechnical solutions. In both cases, however, an intimate cooperation between the geotechnicians and the structural engineers is extremely important.

Most of the disputes taking place in the building industry are doubtless caused by unforeseen problems during execution of the foundation. Of course, problems may occur also when the construction has advanced to the superstructure, but then they are of quite a different nature and mainly restricted to taking care that the structural details during the execution of the building superstructure are in agreement with the prescriptions in the design.

The need for an international standard in geotechnical design has greatly increased in connection with the internationalisation of the building industry. In order to create a common basis for geotechnical design and tendering, a new building code, the so-called Eurocode, agreed upon by all the Western European countries, is being worked out under the auspices of CEN (Comité Européen de Normalisation). Geotechnical design will be treated in Eurocode 7. Geotechnical standardisation work is also carried out on an international basis by ISO (the International Standardisation Organisation). The ISO and CEN committees act in close cooperation. When their work is completed and finally accepted, it will certainly have a great impact on the professional practice in geotechnical design.

As a basis for discussion, the origin of some common disputes concerning the interpretation and realisation of the geotechnical design and execution of foundation works, experienced by the Author, will be presented. Moreover, proper resolution mechanisms will be suggested and put forward for discussion.

ORIGIN OF GEOTECHNICAL DISPUTES

The foremost reasons for disputes can be attributed to insufficient soil investigations. From the client's viewpoint, the money spent on soil investigations may seem unprofitable and sometimes even forced upon him by building regulations. Not being himself an expert on the problems involved in foundation engineering, it is but natural for him to try to minimise the extent and the cost of the investigation. This has entailed a common procedure of inviting tenders for soil investigations, which doubtless hazards the information needed. The economic pressure exerted on the field crew in an investigation received by tender can certainly have a negative effect on the results obtained. This may be the case even where the skill of the field personnel is beyond question. The extent of the investigation, and even the method of investigation, may also have to be modified with regard to the results obtained. These facts speak against tendering; they also speak for a very close cooperation between the the geotechnical expert on the one hand and the field personnel on the other. As a matter of fact, for liability reasons, the field crew and the geotechnical expert, responsible for the interpretation of the results obtained, should preferably belong to the same organisation.

Another frequent cause of dispute is lack of clarity in the geotechnical reports and recommendations. Reports ought to include drawings showing a clear and easily comprehensible picture of the soil conditions at the site. If the field investigation is performed by a separate contractor, all the background data needed for the interpretation of the geotechnical parameters must be included, for example information regarding adopted procedures in their methods of investigation and a careful description of the equipment used (Fig. 1). This is particularly important in the light of increasing international activity on the building market.

Fig. 1. Soil investigations are carried out in many different ways and, therefore, the adopted procedure in the chosen method of soil investigation has to be defined in the geotechnical report.

Clarity in geotechnical recommendations is very important for the cost evaluation of a building project. Thus, if there is a possibility for the contractor, in his tender, to interpret the geotechnical recommendations in a way which is economically favourable, he is legally justified to do so (at least according to Swedish regulations) even if the true intention of the consultant may be disregarded.

Misjudgments of geotechnical parameters used in the design are less frequent, but if these are the cause of a dispute, they may certainly have a more serious impact on the responsibility and reputation of the geotechnical expert in question than other causes of dispute.

As mentioned above, most of the geotechnical disputes originate from insufficient soil investigations. For natural reasons, a geotechnical investigation only represent spot tests (and with regard to groundwater condition only a short-term indication) which must be interpreted by the geotechnical expert to the best of his ability, preferably in close cooperation with geological expertise. However, irrespective of the quality of this interpretation and the recommendations based thereupon, the contractor in most cases will make his own interpretation of the results for the execution of the foundation work. His ambition, as a matter of fact, would certainly be to make a complete and, in the client's opinion, more cost-effective redesign of the foundation of the structure and connecting measures. It is, therefore, extremely important that the geotechnical results are presented in a way to avoid misunderstandings and to emphasise the most important and decisive characteristics of the subsoil, chances of dangerous, or for the contractor costly, deviations from the general characteristics of the soil, environmental problems to be expected during construction, etc.

The problems encountered by the contractor are mainly connected with the shear strength characteristics of the soil and the groundwater condition at the building site. Unexpected groundwater problems, in particular, are a frequent source of trouble for the contractor, often leading to a delay in the construction process and to disputes and claims (Fig. 2). Also, possible existence of boulders, not mentioned in the geotechnical report, can create problems in connection with pile driving, causing damage to pile points and breakage of piles. This will require installation of additional piles and a consequential delay in construction. Furthermore, a misjudgment of the depth to pile bearing strata can infer that a great number of piles will have to be spliced and prolonged or, in the opposite case, that a large percentage of the pile length installed will have to be cut and discarded.

Fig. 3 Groundwater lowering causing subsidence phenomena is frequently an origin of disputes.

Pile installation, particularly in loose granular soil, often entails a devastating effect on adjacent buildings with spread foundations, causing severe cracking and large differential settlements. The responsibility for the damage to buildings caused by foundation work rests on the builder or the proprietor, depending on the type of contract.

In the geotechnical design, the foremost problem to be solved is to make the foundation and excavation design in a way to avoid detrimental total and differential settlements and negative effects on the surroundings. The effect on the groundwater condition by the building activities, possible groundwater outtake, surfacing, etc. has to be foreseen within acceptable limits (Fig. 3).

Fig. 2. Problems encountered during excavation often cause the contractors great concern. Ground failure due to hydraulic uplift.

Since the real soil condition at a building site cannot be revealed in all its details beforehand, immediate action may be required in case unforeseen problems develop in the course of construction. In order to create a basis for such immediate actions, control and monitoring have become an integral part of the construction process. This is generally referred to as 'active design'.

Examples of Origins of Disputes

(i) *Hydraulic uplift*. An illustrative example of the serious consequences of insufficient soil investigations and ignorance of the effect of groundwater conditions is given by the problems encountered in the dry dock at Åndalsnes on the west coast of Norway, intended for the construction of off-shore platforms.

The dry dock, situated at the outlet of the Rauma river, consisted of a 13 m deep excavation with a bottom area of 2 ha. The bottom of the dry dock was 10 m below average sea level. The site is typical of the west coast of Norway with the Rauma river situated in a deep valley surrounded by high mountains.

A preliminary soil investigation, comprising weight sounding in boreholes, with a spacing of approximately 100 m, and sampling in a few boreholes served as a main basis for the evaluation of the geotechnical and geological condition at the site. A completing investigation was later carried out in a great hurry comprising a few dynamic penetration tests, some field vane tests and sampling for soil classification and for determination of the strength properties of the soil. Pore pressure observations were carried out at a maximum depth below the bottom of excavation of 9 m. The completing investigation was mainly concentrated to the north-western part of the site and an area of more than 2 ha was still left without investigations.

The soil at the site was found to consist of river sediments of organic sand and silt covering silty clay with some silt and sand layers and silt/ sand pockets. The clay was underlain by a ridge of sand and gravel wedging into the site of the dry dock from the north-west. The top surface of the ridge was at a depth below the bottom of excavation varying from less than 10 m in the north-west corner to around 20 m in the south-western part of the excavation.

In order to avoid uplift, sand drains, installed to a depth of 10 m below the bottom of excavation, served as relief wells.

As a consequence of excavation and subsequent emptying of the water-filled dry dock, piping occurred in the north-western part of the dry dock. Attempts were made to solve the problems in very costly and partly inefficient ways (cement injection, construction of a diaphragm wall intended to cut off the water inflow from nort-west, deep pumping wells, etc.), causing great delay in the contractor's delivery of the oil platform. (For details of the events, see Hansbo, 1982).

It was obvious that the geotechnical consultant had misjudged the geotechnical conditions. The site investigation was insufficient and, above all, did not reveal the geo-hydrological conditions at the site. After a great number of additional soil investigations, necessitated by the problems encountered, it could be stated that the safety against hydraulic uplift of the bottom of excavation was insufficient. The consultant, in his analysis, had assumed that the hydraulic head in the silt and sand seams to be found in the clay underneath the relief wells would reach a maximum corresponding to the average sea water level. However, pore pressure measurements made outside the excavation, after the trouble had started, showed a hydraulic head of + 3.5 m, *i.e.* 3.5 m above average sea level. Of course, the pore water pressure underneath the dry dock would decrease occasionally due to the decrease in overburden pressure entailed by excavation which might inveigle those concerned into a delusive feeling of safety. Thus, with time the hydraulic head will most certainly regain its original level.

According to the design of the dry dock, hydraulic uplift was doubtless bound to happen.

Due to the heavy economic losses experienced by the contractor, he summoned the consultant before the court. Finally, however, the matter was reconciled with the contractor in order to avoid the consultant's bankruptcy.

(ii) *Groundwater lowering*. This is a case where, in spite of a quite extensive and detailed soil investigation, erratic soil conditions entailed serious problems for the contractor and the client.

The soil at the site consisted of peat and various fill material on deep deposits of partly loose silt and fine sand. Layers or pockets of coarser material were noticed. The groundwater level was situated slightly above the excavation level for the building, except for part of the building area, about 1100 m² in size, where the excavation had to be carried out to a depth of about 3 m below the groundwater level. On the basis of the soil investigation, the consultant presented a detailed plan for the excavation. Groundwater lowering was suggested to take place before excavation of the deeper part of the building area by means of well points (according to the vacuum method).

When the excavation for the deeper part started, a great quantity of water began to flow into the excavation through a vein of water revealed at one of its corners, and it could not be stopped in spite of the pumping being increased to its maximum. The water inflow had to be stopped by plastics injection of the vein of water. However, when excavation proceeded an even heavier water inflow came into existence in another part of the excavation. In order to save money, the contractor and the client agreed on trying to lower the groundwater level by pumping water from a sump. Although 3 m^3/h of water was pumped from the sump for 3 hours, the groundwater level was not noticeably affected. Continued pumping for one week resulted in very large subsidence of the surrounding peaty area. Pumping had to be stopped and the floor of the basement placed at a higher level.

Claims were placed on the consultant for not having revealed in his soil investigation the coarse-grained, water bearing strata. However, these could hardly be characterised as strata but rather as water veins situated between the boreholes in the soil investigation. Therefore, the consultant was acquitted from responsibility.

(iii) *Contractor disregards the recommendations of the consultant*. This is a case showing the importance of intimate contacts between contractor and consultant and mutual information during the construction period.

An industrial hotel was to be constructed at a site with the following soil conditions: 1.4 - 1.8 m of peat and gyttja underlain by 8 - 12 m of soft clay. Raising of the ground surface for a parking space adjacent to the hotel and the consequential settlement to be expected made the consultant propose soil improvement by the use of vertical drains. Lime columns were also suggested in a narrow transition zone between the building, founded on piles, and the drained area. He also suggested that the top layer of peat and gyttja should be removed before the fill was placed on the ground. The time requirement for the use of occasional overloading of the drained area in order to keep future settlement within permissible limits, was specified by the consultant to 6 months.

Three years after the work had been terminated, large subsidence of the drained area had occurred. The contractor stated that it was due to groundwater lowering and that it could, therefore, not be considered his responsibility. However, it appeared that the contractor had ignored the recommendations given by the consultant regarding the duration of overloading (4.5 months in stead of 6 months) and that he, furthermore, had not removed the top layer of peat and gyttja. The contractor's assertion that groundwater lowering had occurred was contradicted by renewed groundwater observations. In consequence, the contractor was made responsible for the subsidence taking place.

(iv) *Negligent contractor*. This is another case where lack of information between the parties concerned and the piling contractor's negligence resulted in serious damage to the building.

A soil investigation consisting of penetration testing had been carried out indicating soft clay deposits underneath a fill of granular material, 2 - 4.5 m in thickness, with a large quantity of boulders. The thickness of the clay deposit varied between 3 and 12 m. Based on the results of his investigation, the geotechnician suggested that the building should be founded on driven, end bearing piles and that due consideration should be taken to negative skin friction. However, the shear strength of the clay had not been investigated and the geotechnician did not inform the structural engineer, responsible for the design, about how to calculate the magnitude of negative skin friction.

The structural engineer, obviously unaware of the importance of the geotechnician's remark, did not account for negative skin friction and the pile loads were consequently underestimated.

The contractor, responsible for the pile installation, did not realise that piles driven into water-saturated clay entail a heave of the ground surface corresponding to the pile volume inserted in the clay, and that this can entail a heave also of the piles previously driven. He, therefore, did not check by redriving whether or not the bearing capacity of the piles already installed had been affected by subsequent installation of piles. Moreover, the contractor had not reacted to the fact that some of the piles had stopped at too high a level in comparison with nearby piles (as a matter of fact, they had stopped against boulders high up in the clay deposit).

In course of time the building was severely damaged due to settlement and had to be partly underpinned. An investigation of the status of the piles showed that some of them had been pulled out of the foundation by negative skin friction.

Claim was placed on the piling contractor for bearing the main responsibility for the damage, but before the case was summoned before the court, the contractor went bankrupt.

(v) *Negligent consultant*. This is an example where the geotechnical consultant was convicted of damage due to misguiding advice.

The soil investigation included penetration testing to the normal extent and taking of undisturbed samples in two boreholes for the determination of the consolidation characteristics of the clay. The soil was found to consist of soft organic clay with a dry crust, about 2 m in thickness. The thickness and the characteristics of the clay deposit varied along the building. Under part of the building, the thickness of the clay was relatively small and the clay overconsolidated. Under the remaining part, where the thickness of the clay was up to 10 m, the clay below the dry crust was only lightly overconsolidated.

The consultant advised his client to found the building on piles and the floor directly on the ground. The settlement of the floor was estimated at a maximum of 100 mm which could be accepted by the client.

After the building had come into use, differential settlement of the floor started to appear, with time greatly exceeding those predicted by the consultant and strongly reducing the utilisation of the premises. The reason why the consultant misjudged the magnitude of settlement was that the samples used for oedometer tests were badly selected and, therefore, not representative of the most compressible part of the clay deposit. Moreover, he had ignored a most probable influence on the groundwater condition by rain water discharge over quite a large area, comprising the building itself and a large parking space.

The client decided to take the consultant to court. According to the judicial decision, the consultant was made responsible for the damage caused to the client and was sentenced to pay the cost of readjustment of the floor level and, in addition, the costs appreciated by the client for reduced possibilities of utilising his premises.

(vi) *Proprietor's responsibility*. This is a case where the city highway department was made responsible for the consequences of public works.

During construction of the Stockholm subway a great number of houses in the city were damaged due to excessive differential settlements.

Due to water leakage into the rock tunnels, when passing fractured zones, the pore pressure in overlying clay layers became strongly reduced and the free groundwater level gradually lowered. As most of the old buildings in the clayey regions of the city are founded on timber piles, often in combination with timber grillages, rotting of the foundations started taking place, leading to large differential settlement.

The house-owners, suffering economic losses due to the construction of the subway, summoned the city highways department, responsible for the subway construction, before the court. Although the case was not as simple as it might seem at first sight, as rotting of timber piles and grillages due to lowering of the groundwater level could be expected to be caused also by sewerage and land heave. However, according to the judicial decision, the responsibility for the damage was laid on the city highway department who was sentenced to pay the house-owners' total costs of restoration.

(vii) *Deviation from code of practice.* This is again an example of a consultant's mistakes.

The case, which concerns two concrete silos for the storage of iron ore, was presented in detail by the Author at the International Conference on Case Histories in Structural Failures, Singapore, 1989. In summary, the design of the silo was based on the German Standard DIN 1055:6 which is in agreement with the well-known theoretical solution presented by Janssen in 1895 and modified by Könen in 1896. However, in one respect he did not follow the recommendations given in DIN 1055:6, namely that the governing silo pressure is obtained when the silo is emptied and not when it is filled. Moreover, he did not consider the fact that the discharge gates at the bottom of the silos were placed eccentrically.

As a result, the silo pressure calculated by the consultant and used as design values was considerably lower than if he had followed the recommendations given in the German Standard. For example, the design pressure according to DIN 1055:6 would be about 1.65 times the value given by the consultant at 10 m depth and 1.41 times the value given at 20 m depth (at the bottom of the silo). The consultant's case was aggravated by the fact that the permissible stresses used in his design of reinforcement were above those accepted in the code.

After the silo concrete walls had started cracking, the storing capacity had to be reduced to about 60 % of its full capacity. Compensation for economic losses was required from the consultant but their insurance company refused to pay. The case was, therefore, summoned before the court. The client lost the case in the district court but won in the court of appeal. According to the judicial decision the consultant was sentenced to pay the client a sum of 2.4 million Swedish crowns and all the costs connected with the trial.

Fig. 4. Cracking of silo walls very costly for the consultant.

RESOLUTION MECHANISM

The resolution mechanism in the case of disputes in civil engineering is either based on arbitration or on court injunction.

In the arbitration process, a restricted number of well reputed experts on the matter and one jurist, generally acting as chairman, are analysing the causes of dispute and their bearing on the problems encountered. The result of their analysis serves as a basis for the assignment of responsibility between the contending parties.

In a court procedure, the outcome of the legal process is rather haphazard. Experts, representing the contending parties, are called in as witnesses to give evidence, both orally and in written form, unto the court. The evidence thus presented serves as a basis for the judicial decision. However, the judicial aspects of the problem may be quite different from the technical aspects and, therefore, many judicial decisions turn out to the technical experts' complete surprise.

As indicated by the examples given above, court injunction is most probably more common than arbitration. As a matter of fact, public proprietors in Sweden have no other choice in the case of a dispute than choosing a court procedure.

In my view, arbitration is by far the best resolution mechanism. Court procedures are usually protracted and costly and the outcome more or less hap-hazardous. It is quite important to avoid long and fruitless juridical processes which only serve the purpose of fattening lawyers' wallets.

SUBJECTS FOR DISCUSSION

The following main subjects for discussion are proposed:

- the present system of inviting tenders for soil investigations
- free-standing field investigation contractors or investigation crews integrated with the consulting firm
- the need for standardisation of soil investigation methods
- framing of geotechnical reports
- the role of the geotechnician in the building process
- Liability conditions in various countries
- Resolution mechanisms in various countries

REFERENCES

Hansbo, S., (1982). Moderator's report on reclamation and waterfront structures. *Proc. 7th Southeast Asian Geotechnical Conference*, Hong Kong.

Hansbo, S., (1989). Two cases of underdimensioned silos. Consultants ordered to pay the damages. *Proc. Inter. Conf. on Case Histories in Structural Failures*, Singapore.