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The Berlin "Neues Museum" – structural analysis, stabilization and structural design for restoration

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Abstract

Due to irregularities within the subsoil and the effects of war, the Neues Museum, which is part of the museum Island of Berlin, is heavily damaged. Fourty years of deterioration caused by exposure to the elements and settlements of the wooden foundation piles have contributed to the continuing decay of the museum. New foundation piles have been built in order to stop the settlements caused by the weak subsoil. The displacements which occurred while the foundation work was on-going were the subject of extensive surveying and testing. The focus of these surveys was to determine which mechanisms of movement were at play within the superstructure and to thereby create a basis for the design of the stabilization elements. The structural stabilization tasks have since been completed. Our primary aim is the preservation of this historical monument, while, at the same time, avoiding any measures which might place restrictions on future internal and external restoration work. Any overall concept must take into account the historical significance of the museum's ceiling constructions – vaults of clay pots, prefabricated cast iron and wrought iron girders. Once more, the main priority of any such concept must remain the preservation of these remarkable structures.

Introduction

The Neues Museum is located on so-called „Museum Island“, an island in the River Spree in Berlin, together with a number of other museum buildings. The subsoil found in this area is characterized by unstable Holocene inclusions in the firm Pleistocene layer – not surprising given the fact that the building is situated in what was once part of the pre-historic Berlin-Warsaw river valley.

Thus we are dealing with crater-like sheer drops throughout the firm bearing stratum. Of all the buildings on the Museum Island, the Neues Museum is the one most negatively effected by this type of inhomogeneity. From the southeast corner to the northwest corner, the level of the firm soil layer falls to almost 25 meters below the undersurface of the building's foundation. (Figure 1.)

Back when the building was originally under construction, the builders were aware of the problem but decided that it could be solved by providing the edifice with a wooden pile foundation. As the length of the wooden piles was limited, the original builders used „floating" wooden pile raft footings for the northwest section. (Figure 2.) This foundation had already caused so much settlement damage by the time the building was opened in 1855 that renovation became necessary shortly thereafter.

Longterm lowering of the groundwater level, which coincided with the construction of neighboring buildings, further contributed to the problems, leading, as they did, to a parasitic infestation of both the wooden pile foundation as well as the timber raft resting thereon, which in turn led to the rotting of the pile foundation grilling and the pile butt ends. In addition, the area around Museum Island was heavily damaged during the war, particularly by bombs and shell bombardment. Fourty years of unprotected exposure to the elements took further toll on the ruins.

In the mid-eighties, the government of the former German Democratic Republic (East Germany) decided to restore the Neues Museum. Upon salvage and recovery of the remaining exhibition pieces, a large number of building components were torn down and cleared away. Particularly significant here is the fact that the most severely damaged northwest wing and the south dome, complete with the passageway to the Altes Museum (old museum), were removed entirely.

Restoration of the foundations

By the time Germany was reunited, an offset piled bearing plate in the former northwest wing area and a compensating foundation for the neighboring walls had already been put in. Following German reunification, our offices were entrusted with the completion of these measures. Our work has been sponsored by the „Stiftung Preußischer Kulturbesitz" (a trust established for the maintenance of Prussian cultural artifacts) under the supervision of the Bundesbaudirektion (federal building authorities).

Our first task was to inspect the previously built load-transfer structures as to the effectiveness of load transfer from the walls to the newly built-in pilings/underpinnings. The builders in the former German Democratic Republic had chosen to use „high-tech" construction methods with stainless steel pegs and tie rods of prestressing steel. These structures, however, put

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heavy strain on the historical masonry. (Figure 3). We countered with „robust" construction (Figure 4), which meant less overall drilling into the historical building substance, which called for only general purpose contructional steel and which caused less strain on the historical masonry.

Upon consideration of both constructional as well as economic aspects, our robust construction measures were given preference for the work on the remaining walls. The piling used consisted of small-scale bored piles in the form of composite piles – a construction method considered to be highly unusual in the days of the former German Democratic Republic. Since reunification, an officially approved pile system, also consisting of composite piles, has been implemented. A total of 2,568 piles, each measuring anywhere between 9 and 32 meters in length and amounting to an overall 50,000 lineal meters, were driven in between 1990 and 1994.

Testing and surveying procedures

In conjunction with and parallel to the work being carried out on the foundations, the building was the subject of extensive surveys and testing with the aim of monitoring any structural displacements during the course of the foundation work. These surveys also served to provide us with the necessary data to be able to react with appropriate preservation measures should drilling stresses cause any substantial structural displacements. After German reunification, the test and survey results were evaluated systematically in respect to the preservation of the superstructure. Such surveying is still being done, albeit with reduced scope.

Evaluation of tests and surveys as regards settlements

Upon comparison of critical points in terms of construction progress and survey results, we have reached the following conclusions:

- Drilling stresses considerably increased settlements (Figure 5).
- These are settlements which would also have occured without drilling stress, although in that case these settlements would not have happened within such a short period of time.
- Periods of drilling further revealed a clear picture of the mechanisms of movement which were already inherent to the edifice and which stem from damage caused by the inhomogenous foundation situation. The data gathered thereby provided the basis for decisions regarding appropriate superstructure stabilization measures. (Figure 7)
- Upon completion of the piled bearing plate, the results of wall testing and the results of tests conducted on the piled bearing plate proved to be identical, thus demonstrating the efficacy of the load transfer stuctures.

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- The secondary settlements which have taken place since the piled bearing plate has hardened are insignificant. The uneven settlements of neighboring points, which were to be expected, are acceptable and can be handled by the superstructure (Figure 6).
- It must be assured that this uniformity in terms of displacements and deformation is not lost when the superstructure is rebuilt.
- Some localized damage may result from uneven settlements.

Stabilization/preservation of the superstructures

The stabilization/preservation measures were planned and executed at a time when there was still no architectural design for the final restoration of the building. In consequence, the following principle had to be borne in mind throughout both planning and execution:

The stabilization/preservation of the building mass, as is, while avoiding any measures which would restrict future internal and external restoration. Any and all measures taken must be either reversible, in as much as this is possible, and/or be suitable for use in the final restoration of the building.

Preventative measures were executed immediately to prevent further damage to statically significant fissures which were endangering the stability of the structures. Once the point had been reached where no more heavy settlements were to be expected, the following measures were carried out (Figure 8);

the joints between the individual wall plates and building components were bridged,

no-longer standing stiffening walls were reincorporated into the overall structure.

In as far as it was constructionally necessary (protection against exposure to the elements), smaller, not statically significant fissures were also secured. Finally, the remaining ceilings' capacity to carry the weight of those walking on the floors above had to be evaluated. Those ceilings which were not safe had to be made so for the interim.

Preservation of the historical ceilings for future use

Existing ceiling systems

There are a number of different and quite remarkable ceiling systems in the Neues Museum and these ceilings provide a significant contribution to making the Neues Museum unique in its capacity to provide evidence of our heritage. With the primary aim of reducing the weight of the building, given the poor subsoil support which was referred to at the beginning of this paper, the original builders built the ceilings on the upper floors out of clay pots embedded in gypsum morter. Such clay pots were used for cradle vaults, dome roofs, cellar vaults and light wall-lining.

The Neues Museum was the only building in all of Germany at that time in which cast iron was used for flexible beams, for arch elements, for the support beams of framework construction and for braces. Building parts made of wrought iron were used for braces in brickwork and masonry, for tension rods in ceilings and for beam ties on bowstring girders. Various types of masonry were used, as were appropriate, for columns and pillars, for walls, arches and for vaults.

Material characteristics

When determining whether the ceilings/floors are safe for construction workers to work on and for groups of visitors to walk on, we are basing our decisions on historical records, survey plans and drawings of the structures as they are as well as on additional material testing. Determining the characteristics of the bricks is not difficult. It is the clay-pot vaults which pose problems. We have a test report at our disposal, dating back to when the Neues Museum was originally built, as well as some, albeit insufficiently documented, compression tests conducted prior to 1990. These provide a basis for our evaluations. In addition, calculations have been made on statically simple systems such as vaults.

The cast-iron building materials themselves must be divided into two different varieties; building materials which were manufactured in the Royal Prussian Foundry and those which were manufactured in the Borsig Foundry, whereby the latter are, without exception, of higher quality. This is probably due to the quality assurance systems which were already standard practice at Borsig at that time. Cast iron itself is a brittle material which is prone to fracturing suddenly and without warning and the performance of which varies greatly depending upon whether the stresses are compressive or tensile in nature. This material reacts very sensitively to faulty spots in areas of tension stress (notches, damages incurred during wartime, etc.). Production quality also varied greatly. In order to determine the characteristic values of these materials, we have conducted tests on debris removed from the ruins and compaired the results with existing, documentated data.

The wrought iron which was used is considerably more ductile than cast iron. Wrought iron does not fracture without warning and any fractures will occur only after material deformation has first taken place. The materials which were used are suitable for use in areas with tension stress. We know for sure that the braces of the bowstring girders were tested before being put in as were perhaps other parts as well. We have relied both on fracture tests conducted in the past as well as on recent tests conducted on debris from the ruins when determining the characteristic values of the materials used.

Results of initial ceiling calculations

Initial calculations came up with a preliminary admissable imposed live floor load for the cellar ceiling of $p \geq 5kN/m^2$, whereas that for the lighter ceilings in the upper stories was only $1.0\ kN/m^2 < p < 3\ kN/m^2$. The only areas which had to be completely closed off were on the uppermost floors in the south wing as here a qualified evaluation of the permissable loads was not possible - partly because of substantial damage and because of the danger of localized weaknesses resulting from insufficient load distribution caused by no longer existing floor coverings and partly because such evaluations would have overshot the budgeting at that time. This will mean that, afterwards, further work will have to be done on a number of the ceilings.

The German 1045 DIN standard calls for an imposed live floor load capacity of $p = 5\ kN/m^2$ for a building being used as a museum, whereby some types of exibitions will surely call for stronger load-carrying capacities. At present, those involved (the architect, the user, those concerned with the protection of historical monuments and the engineers) are discussing possible utilization concepts for the structure with the aim of making it possible to use the building as a museum while infringing on the integrity of the historical building as little as possible. This would mean, as regards the historical areas, trying to make use of the possibilities which the historical structure has to offer while, at the same time, not forcing compliance to the very letter of the more generalized requirements of the DIN standards.

The concept for the very first exibition at the Neues Museum already managed to take the various supporting structures into account. Even the upper floors held heavy exhibits. These exhibits were simply placed either near the walls or directly over braces but never out in the middle of the ceiling area. Why shouldn't similar concepts be made to work for the final, restored building as well?

The possibility of increasing the imposed live floor load capacities

From today's point of view, the maximum permissable imposed live floor load capacities are all but satisfactory. Various ways of increasing the capacity of the different ceilings are open to us:

Theoretically,

- via additional material testing (individual sampling and/or building section testing),
- on-site material testing, such as the testing of cast-iron tension booms for fractures,
- test loading, on-site in the building.

Practically,

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- by equipping the building with compensating systems which prohibit the less stable areas from being directly exposed to any imposed live floor load (such as double-bottom constructions) or
- reinforcement and securing of critical zones on certain load-bearing elements, whereby the cast-iron beams come especially to mind. We are presently putting together a test program which would determine how these beams would behave if reinforced with glued-on, carbon-fiber lamellas.

Summary

Prior to 1998, the preservation of the remaining substance of the building was the primary objective. The foundation was stabilized. The solidium of the superstructure, which had fallen apart into numerous individual pieces, was tied together to form a monolith. Interim maximum permissable load capacities were determined.

Right now we are working on concepts for the building's future use as well as on the development of any ceiling reinforcements which such concepts might call for. The restoration of historical buildings means suspense for the planners of the supporting structures, too!

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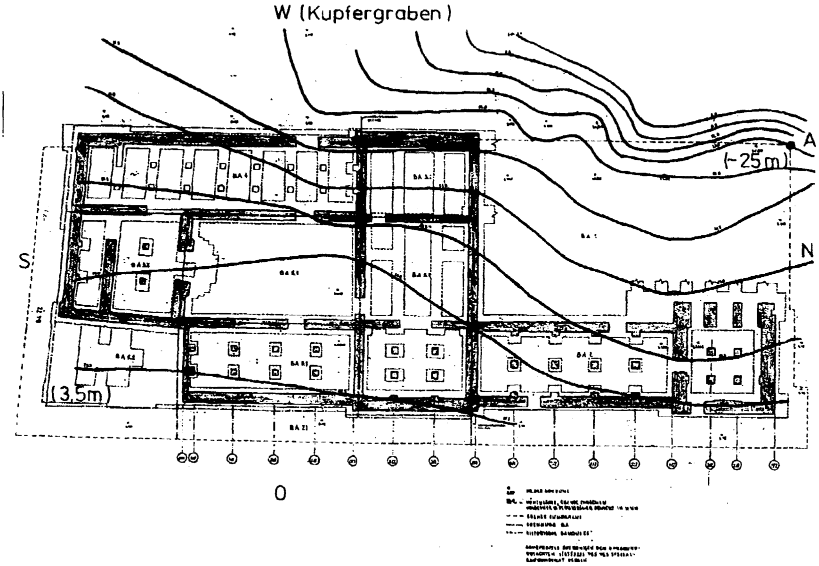

Figure 1: Contour lines of the firm subsoil layer

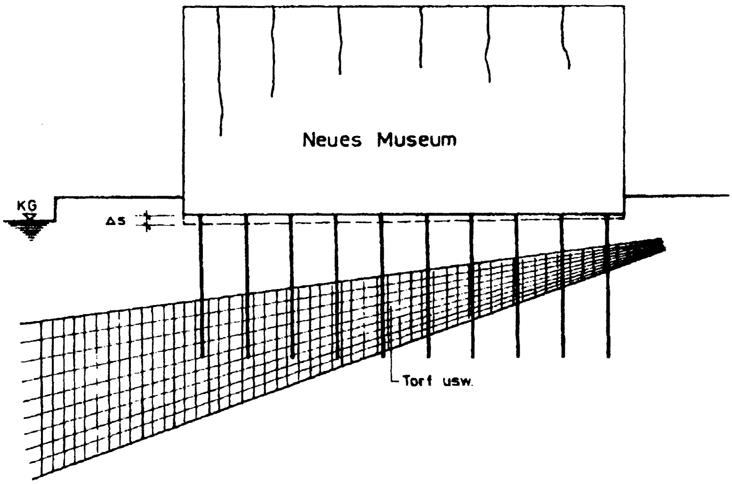

Figure 2: Cross-section of the foundation situation

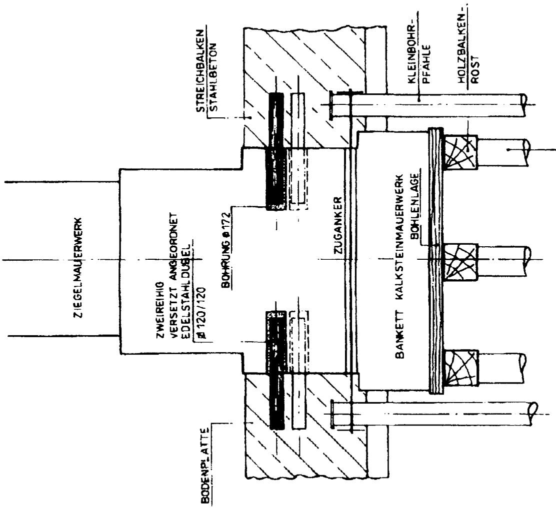

Figure 3: Load-transfer structures prior to German reunification

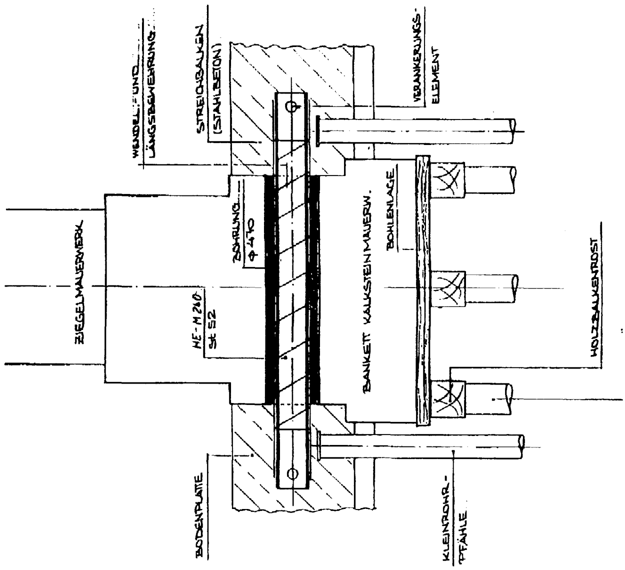

Figure 4: Load-transfer stuctures after German reunification

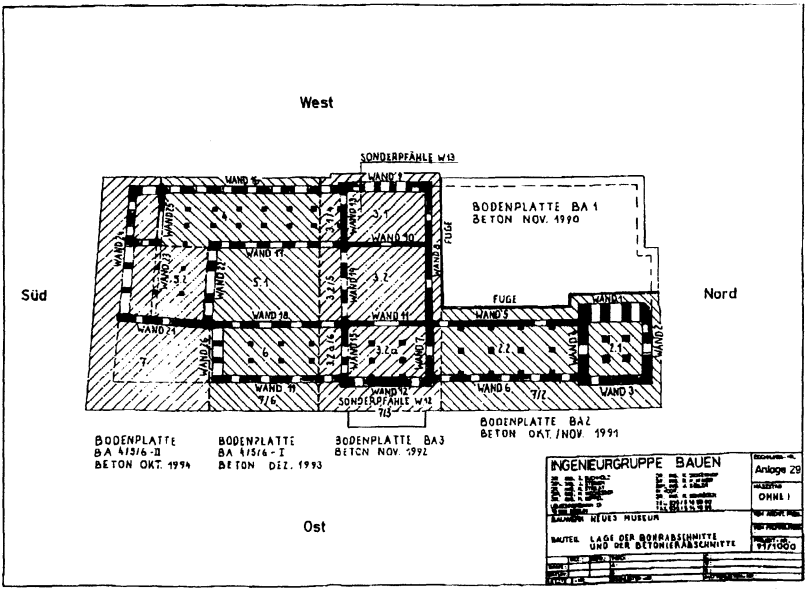

Figure 5: Ground plan of the remaining cellar walls
Construction divisions

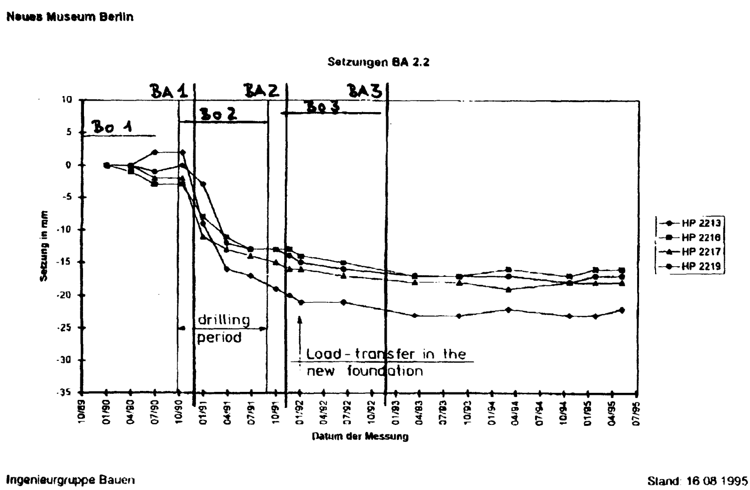

Figure 6: Evaluation of the surveys and tests for settlements
(exemplary)

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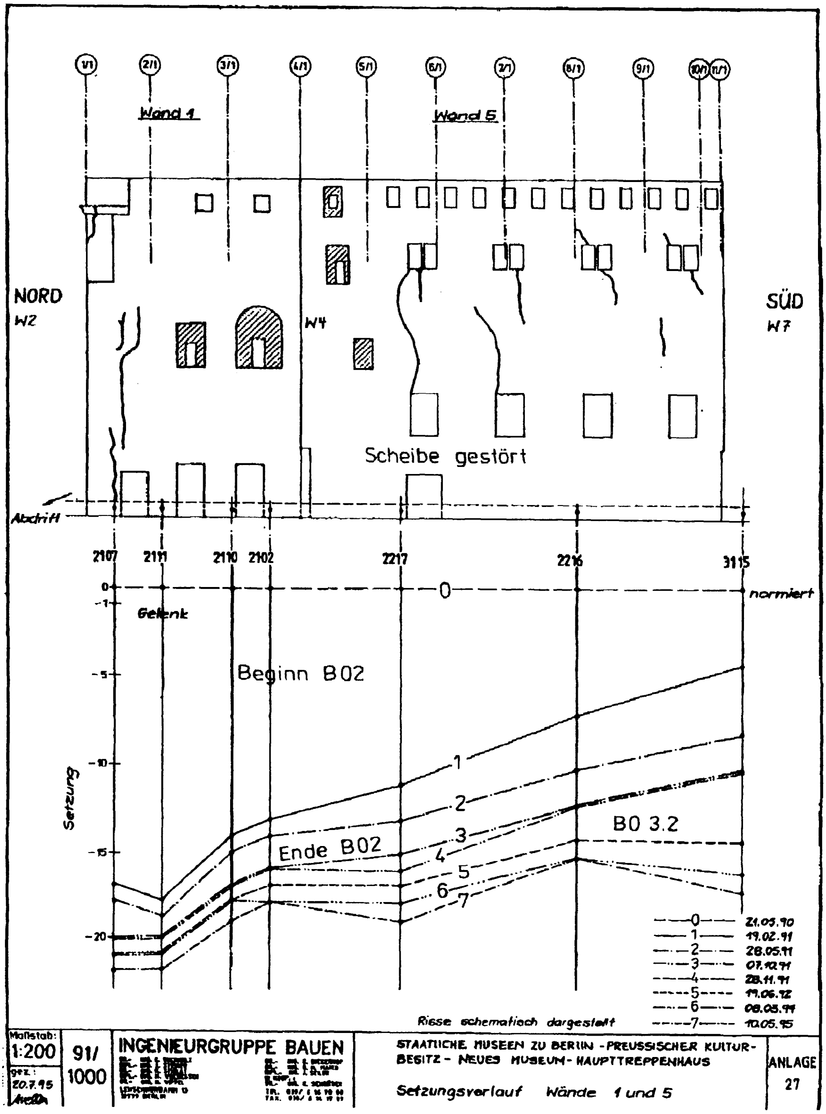

Figure 7: Assessment of the mechanisms of movement (exemplary)

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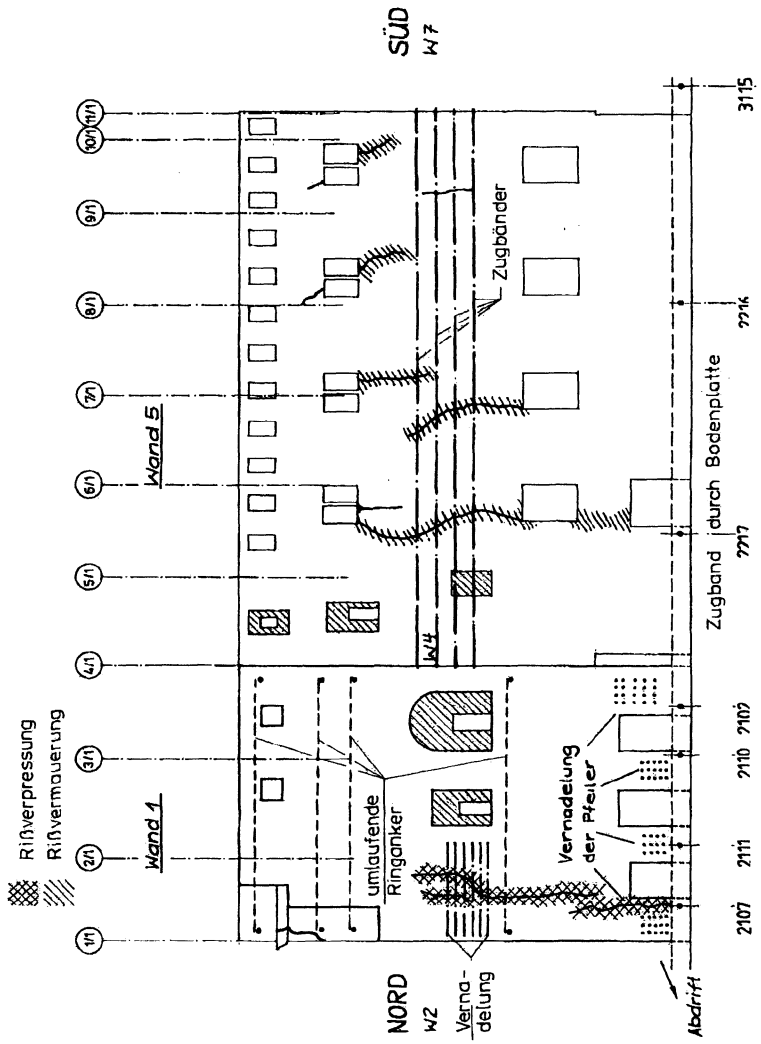

Figure 8: Outline of the stabilization measures carried out, with wall 1 and wall 2 as models.