THE DESIGN OF THE INSTALLATION AND OFFSHORE COMPLETION OF THE EKOFISK PROTECTIVE BARRIER

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SUMMARY

In 1989 the Ekofisk Protective Barrier was completed around the Central Ekofisk Storage Tank. The Ekofisk field, 400 km east of Edinburgh, is a very important junction in the Oil producing and transporting Northsea network. The protection of the Tank was necessary due to increased wave loads caused by subsidence of the seabed. The installation and the subsequent offshore connection of the two caissons of the Protective Barrier was critical and complex. This was related to three aspects, which were influenced by many interrelated parameters. The three aspects were tolerances of the joint construction, the stability of the uncoupled halves during the temporary phase offshore and the strength of the joint construction.

Given the extreme time pressure (18 months for the total project), the design of the installation and offshore completion was coordinated by dynamic models of aspect systems. This coordination system and the reasons why it was developed is described in this paper.

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1. INTRODUCTION

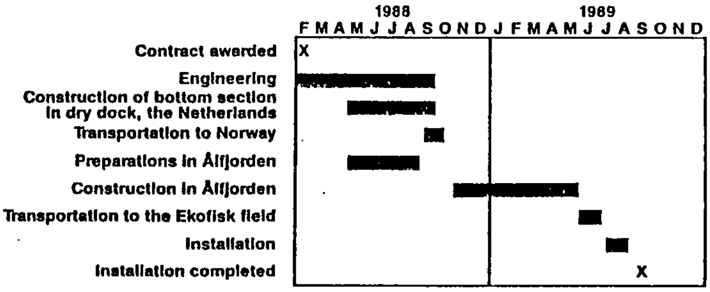
In 1987 it was necessary to elevate the decks supported by steel jackets at the Ekofisk Field due to significant seabed subsidence which resulted in an increased wave load. However, in order to prevent any production shut down, a different solution was required for the central concrete bottom founded tank, supporting the main field processing facilities. The solution adopted was a bottom founded concrete protective barrier surrounding the existing tank structure, installed in two separate half units. These units were connected by a joint construction of steel plates to be inserted into prepared boxes within each unit. After placing of the plates, the space between the two half units was concreted in order to provide the necessary structural strength. The Engineering, Procurement and Construction contract for the project was awarded to Peconor Ekofisk AF in 1988 and the protective barrier was completed in autumn 1989.

2. SPECIFIC PROJECT CHARACTERISTICS

The concept of the Ekofisk Protective Barrier is rather unique. Firstly, it was the first offshore construction which was not installed as a monolith. Secondly, the shape and mass of the construction was different from all realized structures in this construction discipline. Thirdly, the wave load on the structure during both the constructional phase as well as the utilization phase is beyond the load on any other existing offshore structure.
The most significant characteristic of the project however was the available construction time with respect to the size of the Protective Barrier. Phillips Petroleum Company (PPCON) had 18 months available from basic concept to complete protection. PPCON's development philosophy was based on two main components in order to avoid any further delay:

- Develop the protection system within an EPC contract to avoid interface problems and associated time losses;
- Round off the conceptual design phase completely, fix the concept and keep the engineering as simple as possible.

The contractual time schedule was rather tight (fig.2.1).



A construction period of 18 months,
and a contract value of NOK 1.5 billion.

Figure 2.1

The basic idea behind the schedule was a straight forward engineering of isolated subsystems of the concept for a period of eight months, followed by a subsequent construction and installation phase. The above philosophy is acceptable in case the system to be developed meets two criteria:

- The system may not be complex.
- The concept must have sufficient reserve to compensate negative consequences of initial uncertainties.

Given the extreme time pressure the non-fulfillment of at least one of the two conditions leads to a frustrated development process. The main reason is complexity. Complexity is defined as the rate in which the whole of the system differs from the sum of the parts. This difference is mainly caused by interrelations. In consequence, the behaviour of a complex system can not be predicted with the behaviours of the isolated separated part only. Hence, in case the concept does not have enough reserve, the whole system must be considered.

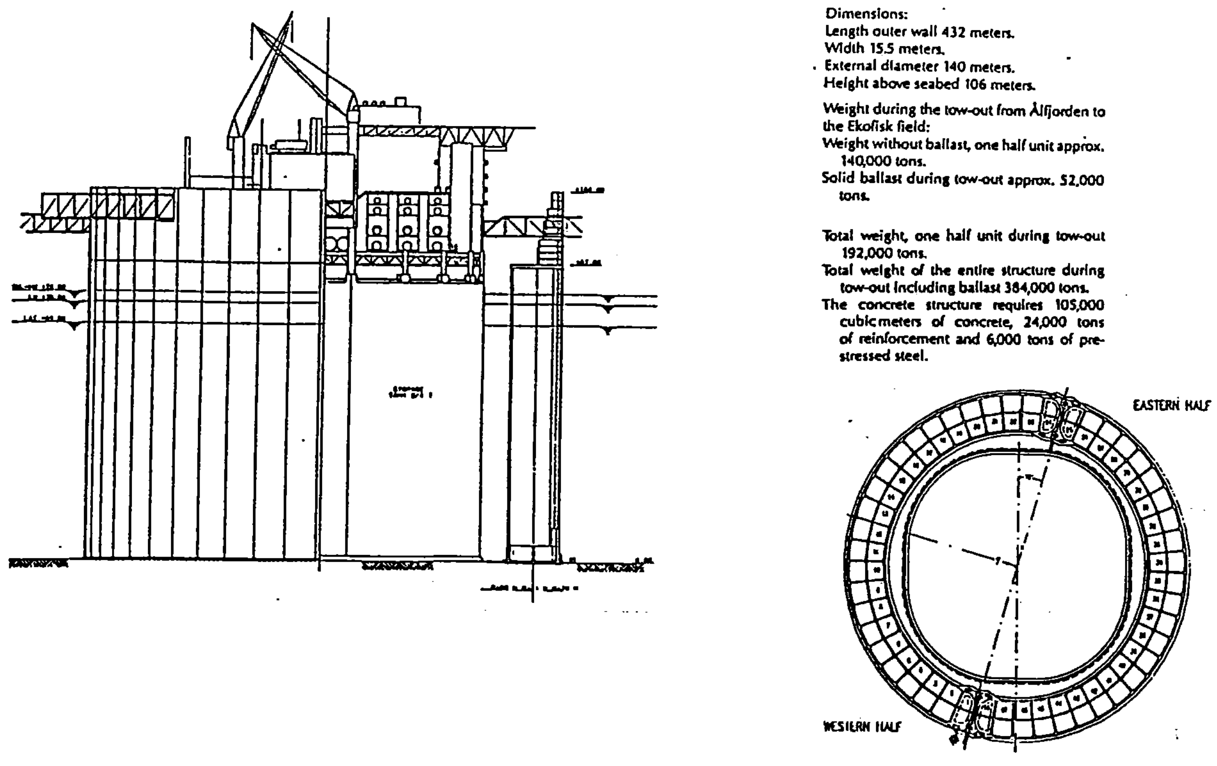
3. THE CONCEPT AND ITS ENVIRONMENT AT THE START OF THE PROJECT

The environment was described as follows:
- 100 years wave condition for the in-service period.
- 10 years summer wave condition for the temporary phase offshore with both half units uncoupled.
- Type of soil, strength related to soil data at a few hundred meters distance of the tank, margins.
- Lay out of platforms and pipelines

For the Barrier concept the following items were investigated:
- Global structural analysis
- Wave load on uncoupled half units
- Wave induced motions on floating half units

Environment and conceptual design resulted in:
- Dimensions, construction material and lay out
- Principle of joint connection
- Guaranteed stability of uncoupled half units during the period june-september.

A horizontal cross section of the Protective Barrier and a side view is given in figure 3.1.



Dimensions:
Length outer wall 432 meters.
Width 15.5 meters.
External diameter 140 meters.
Height above seabed 106 meters.

Weight during the tow-out from Ålfjorden to the Ekofisk field:
Weight without ballast, one half unit approx. 140,000 tons.
Solid ballast during tow-out approx. 52,000 tons.

Total weight, one half unit during tow-out 192,000 tons.
Total weight of the entire structure during tow-out including ballast 384,000 tons.
The concrete structure requires 105,000 cubic meters of concrete, 24,000 tons of reinforcement and 6,000 tons of pre-stressed steel.

Figure 3.1

4. GENERAL DESCRIPTION AND EVOLUTION OF THE JOINT CONNECTION

After the inshore completion, the two caissons of the Barrier were towed in floating position to the Ekofisk field. The subsequent installation was as follows (fig 4.1):

- Approach of the western half unit and positioning of the rotating point above the already installed docking pile
- Rotation of the western half unit around the docking pile till the desired position is reached. Rotation impact is taken by a bumper fender, attached to the innerside of the western half unit.
- Lowering by water ballasting
- Underbase grouting after sufficient penetration, in order to provide enough stability.
- Approach of the eastern half unit and positioning the topside at a distance of 1 meter from the western half unit with top fenders.
- Tilting of the eastern half unit with differential water ballasting till contact is made with the lower fenders.
- Lowering by water ballasting and after penetration underbase grouting

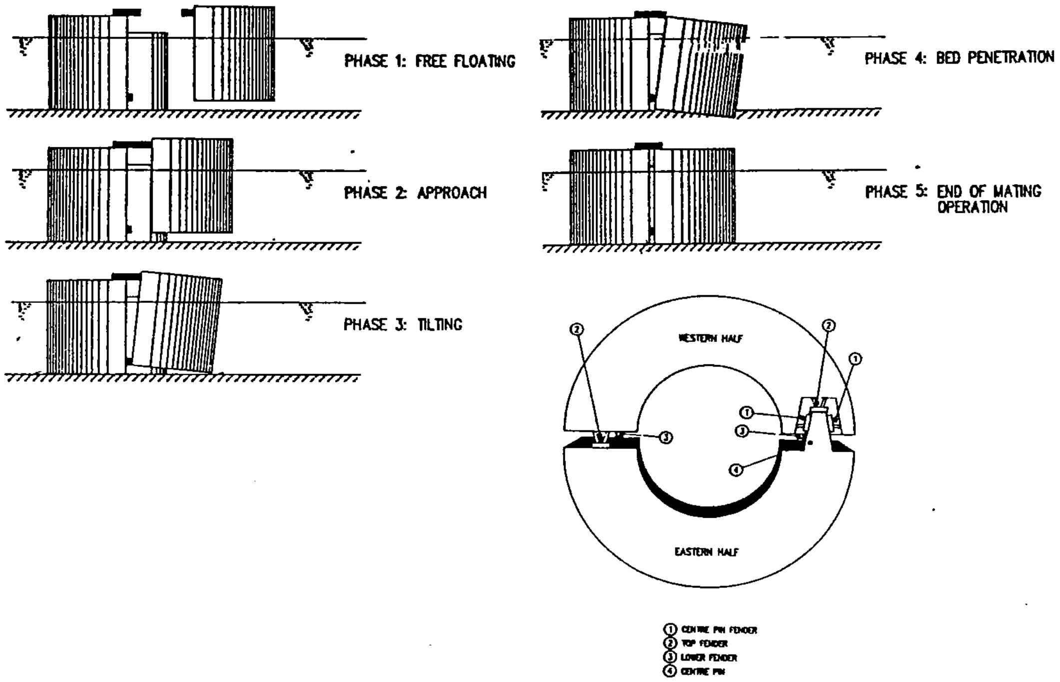


Figure 4.1

PRINCIPLE SKETCH OF MATING SYSTEM DURING TILTING.

After installation, the two half units had to be coupled in order to provide enough strength and stability to withstand the design wave condition. The concept was based on a connection of the inner and outer walls, which was to be provided by key piles to be inserted in circular recesses in keys and in-situ concrete to be casted in the remaining holes. This concept is sketched in figure 4.2.

A few months after the start of the project, it was concluded, that the magnitude of the forces to be transferred in the lower part of the joint, were substantial larger than assumed. In consequence also a connection of the bottom slab was necessary. Due to several reasons (strength, fatigue, construction problems, etc.), the key and key pile concept was after seven moths engineering changed into a steel plate and prepared box concept. At that time the lowest keys were already constructed. The changed joint concept is sketched in figure 4.3.

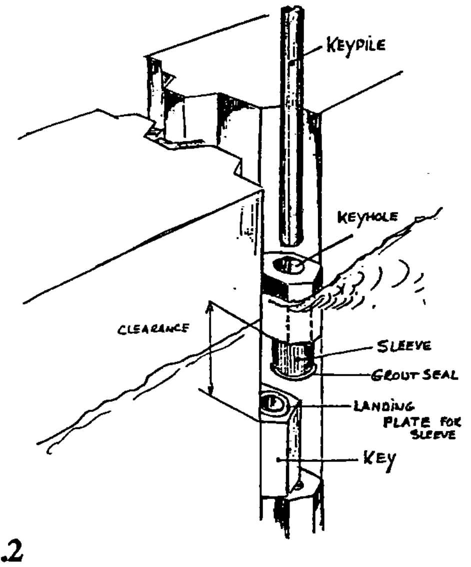


Figure 4.2

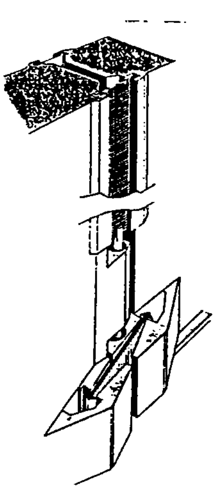


Figure 4.3

5. THE PROBLEMS WITH INSTALLATION AND OFFSHORE COMPLETION

5.1 Events during the engineering

A few months after the start of the engineering, model tests on wave loads revealed that the wave loads with the defined 10 years summer storm condition on the uncoupled half units were twice as much as assumed. Due to the larger wave loads and given the defined soil condition, the stability of the uncoupled half units was not ensured during the temporary offshore phase at Ekofisk. Stability could be insured by increasing the amount of ballast. However, a larger amount of ballast would cause larger differential penetration and settlements due to non-uniform soil conditions. This would lead to horizontal tolerance problems (figure 5.1). Due to the tolerance problems, it was advisable to limit the amount of ballast prior to joint connection works. Unfortunately, such a ballasting strategy would lead to larger built-in stresses due to deformations after the connection works, (fig. 5.2).

Figure 5.1

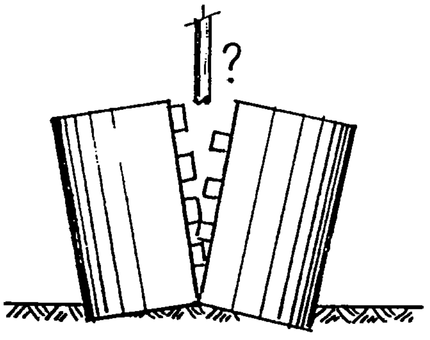
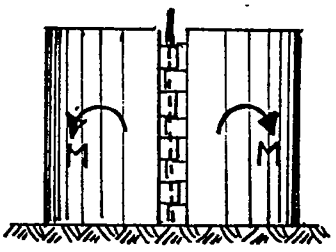


Figure 5.2



Confronted with the stability problem, PPCON was willing to accept more risk during the offshore phase and lowered the summer storm condition. Instead of a 10-years return period, a 3-years return period was allowed for the governing wave condition. However, even this wave condition was too heavy to ensure stability. Besides that, the tolerance problem would remain. Model tests on floating behaviour resulted in larger wave induced motions as assumed during the floating position prior to installation of the second half unit. In order to avoid clashes two measures were necessary. Firstly, the gap between the two installed halves was enlarged. As result the amount of concrete to be poured into the gap became larger and consequently the necessary concreting time offshore. Secondly, the vertical space between the keys was changed to allow for vertical motions.

The larger gap and the required hardening time required a minimum concreting period of one week. During this week motions were not allowed in order to guarantee adequate strength development. This additional requirement made it necessary to find a week in which the wave action had to be negligible.

6. THE DESIGN APPROACH

6.1 Analysis

The overall design problem with the three critical aspects during installation and offshore completion (tolerances, stability and temporary strength) pointed out that there existed contradictory requirements on the coupling philosophy in relation with the ballasting strategy:

- The tolerance problem would be less critical in case the amount of ballast prior to the connection is at minimum
- The stability of the uncoupled halves and the strength of the joint would be less critical in case the amount of ballast is at maximum as soon as possible.

An examination of the design problem showed that a large number of variables were related to the governing aspects. A simplified logical interrelation scheme is given in figure 6.1.

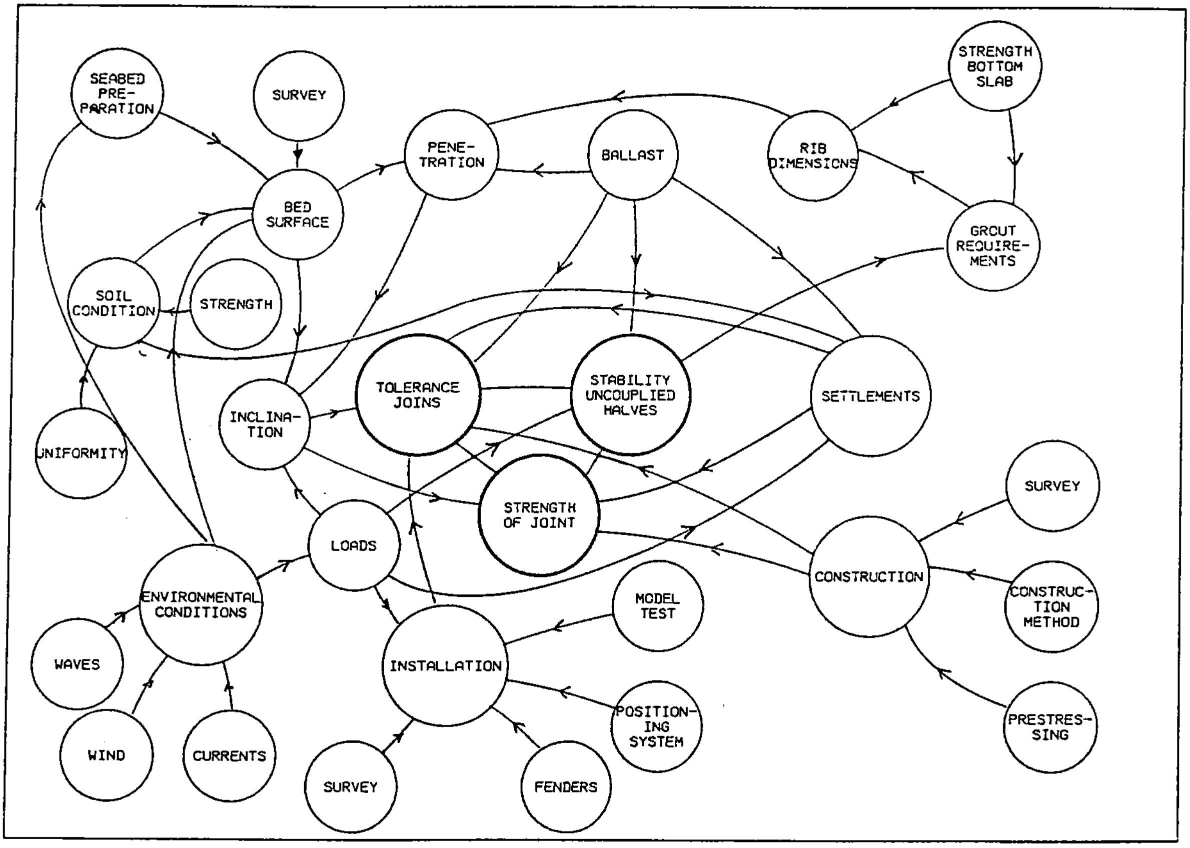


Figure 6.1

Without doubt the temporary phase offshore could be considered as a complex system. The development of that system was complicated due to four factors:

- Major boundary conditions e.g soil condition and wave climate were unknown.
- Behaviour of the total temporary system was influenced by changing stochastical boundary conditions.
- The solution of these design problems was urgently required, as the construction works had already started.
- The offshore installation works tentatively had to be advanced (more favourable wave climate), which caused even more time pressure on the overall development scheme.

Due to these facts the total development process changed from a phased engineering and construction into a simultaneous engineering and construction development process. Consequently, the planned eight months engineering period lasted over the full construction period.

6.2 Development strategy

The only way to solve the design dilemma without iterations was to describe the total behaviour of the installation and subsequent offshore completion with respect to the critical aspects in a mathematical model. This model could be used as an overall coordination organ. Therefore it was necessary to have insight in both strength and uniformity of the soil as well as the wave climate during the summer months. Both boundary conditions played too important a role to suffice with a sensitivity analysis of the uncertainty of the soil and with schematized unfavourable wave data valid for the defined four months installation period. On Peconor's request soil and wave climate investigation was started. Since the behaviour of the total system was dominated by transient stochastic parameters, the model to be developed had to be a simulation model. Given the urgency and the main purpose (coordination), the following modelling philosophy was adopted:

- Keep the models as simple as possible and split up where possible. (modules).
- Develop the models from rough to fine. The visualization of the interrelations is more important than the overall validity.

6.3 Coordination by dynamic models of the aspect systems

Two principles were used for the coordination of the design of the installation and offshore completion. The first principle is coordination with meta control. With the Peconor organization, composed of homogeneous clusters (disciplines) of C.T.R's (Cost, Time, Resources units), the controlled system is the subset of relevant CTR's within a discipline. The discipline leader is the control organ. The metacontrol takes over control function in case the control organ is inadequate or incompetent. In fact the control is inadequate in case solutions of design problems have to be found outside the discipline. The second principle is meta control by aspect systems. In order to avoid large iterations when developing a complex system under time pressure, it is wise to coordinate on interrelations. Since aspect systems are defined as subsets of interrelations, they can be used as coordination (metacontrol). For effective control, it is necessary to make dynamic models of aspect systems.

7. THE DYNAMIC MODEL OF THE TOLERANCE ASPECT SYSTEM

7.1 General

A detailed analysis of the fitting of the joint constructions pointed out that a deterministic approach of the influencing processes would lead to unrealistic joint dimensions. Due to the two dimensional problem as a function of the height, and the stochastically independent processes, a Monte Carlo simulation model was developed, with three main components. Firstly the concept and the design variables, secondly the environmental boundary conditions and thirdly the processes.

The tolerance model was developed for the temporary phase after installation of both half units. In consequence clashing possibilities during the mating operation (western half unit installed and eastern half unit floating) had to be dealt with at CTR level.

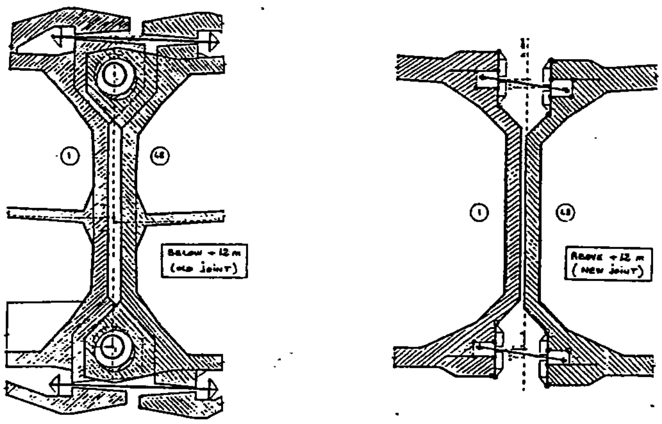
7.2 The concept, design variables and the geometrical model

The fitting problem was concentrated on two typical cross sections e.g. above and below El +12m (figure 7.1) and concerned the fitting of the connection plates and keys into the associated recesses. The direct design variables were:

- diameters lowest keyholes and key piles
- dimensions of the boxes
- length of the plates
- dimensions of the wing wall recesses

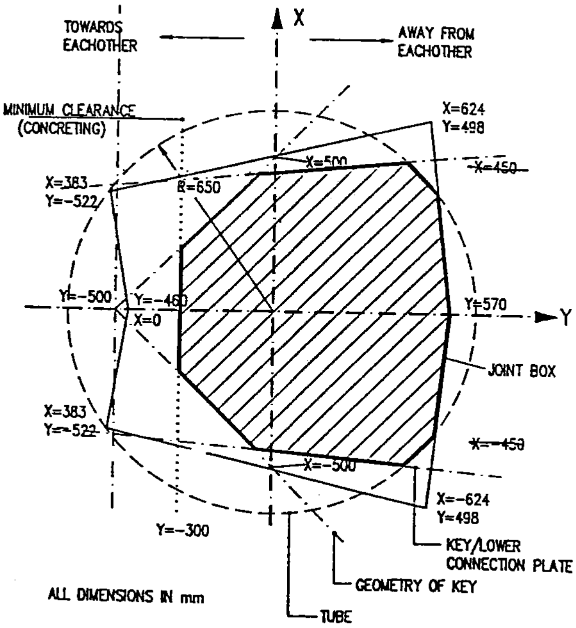
The coordination on tolerances eventually resulted in an optimal choice of the above variables. The resulting composite chart of clearances of the final design, showing the available tolerance space, is given in figure 7.2.

The tolerance considerations were necessary to deal with deformations, deviations and displacements of the two installed half units with respect to each other. These processes had to be determined and combined into a geometrical model. This model was built up in three dimensions with translations and rotations. Hence the position of any arbitrary point on the two half units was given in coordinates.



POSSIBLE HORIZONTAL DEVIATIONS IN THE JOINT

Figure 7.1



AVAILABLE CLEARANCES AT LEVEL h=12m

Figure 7.2