Day 2

Part 2

Quality Assurance in the Design Process

Trends and Incidents

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1. WHAT IS NEW IN THE QUALITY APPROACH

Although Quality Assurance in manufacturing and construction has been explicitly introduced, Quality Assurance in the design process is practised far less.
The reason is quite clear. Design work is generally looked at as code checking which is thoroughly performed by building authorities, certifying bodies or consultants asked to perform such a code check.
In Germany special institutes such as "Prüfer" and "Gutachter" have been established. Quality is in fact traditionally established by code-checking done by third parties.

This is, however, not the aim of modern Quality Assurance systems as intended by the ISO 9000 code. This approach deals with the quality of the total process of design, which in fact leads to more or less effective designs, both still according to the code.
This chapter explains about the basic characteristics from which people perform a design task and it explains about the different tasks and processes required in a quality assured design process.
These paragraphs are checked against the accident with the Sleipner platform in 1991 in Norway, in order to show that a sound quality system can prevent such disasters.

2. WHAT CHARACTERISTICS ARE REQUIRED FROM DESIGNERS; FROM GOOD OR WRONG TO BETTER OR WORSE

Any designer starting in a design team has some basic training. During their training at the university the first objective was to achieve that the students obtained a certain **understanding** of the basic principles of the domain of the subject being taught. It was further envisaged to transfer a certain amount of formal **knowledge** towards the students. Having achieved these two points, the student was trained to use these in order to solve problems, which in fact trained him in **abilities** within the domain he was trained in. In some cases it might even have been possible to appeal to the awareness of the student in order to train him to develop a certain **attitude** in approaching certain problems to be solved when he is confronted with them.

The amount of attention to be paid to understanding, knowledge, abilities and attitude individually is however a matter of constant conflict, as the sources of development of these elements of training objective constantly develop.

Understanding in for instance material behaviour is permanently influenced by **research** in materials all over the world.
This constant change in findings from material research, affects for instance the understanding of the **behaviour** of structural components. This, in turn, effects the development and presentation of **rules and codes** on a national and international basis, such as in Europe for instance the move from national codes to the Structural Eurocodes.

Some understanding of material behaviour, component behaviour and of the interaction between components has to be present, as well as the knowledge of rules in order to design a structure. This means that in this case the design process may only be a trial and error exercise of randomly checking generated structures on codes.

When a formal design process is developed, code checking a design can be anticipated to be successful. The **design process** is then not trial and error, but a cyclic process of **material selection, shaping and sizing**. In order to perform this properly, the **objective** of the whole process has to be clear, meaning that questions such as "should the lowest price for construction be achieved, or the lowest integral price for construction and maintenance?", should be asked. Other questions may also arise, such as "should the structure with the lowest risk of budget exceeding be designed, or the structure with the lowest impact on the environment?". It is really a matter of attitude whether designers approach their task in such a way, instead of merely concentrating on the smallest amount of quantities.

Viewing the world of primary and secondary education this way, it should be clear that a textbook on research and material behaviour is structured differently from a textbook on design. The same is true for the structure of codes. Codes are basically there to check structures already designed and detailed, meaning that shape, material behaviour and sizing have been fixed before the code is used.

During the design process, where shape, material and sizes are fixed, codes are only used in the sense that the design process anticipates later code checking. This means that documentation and accuracy of the initial design process can be less severe and is differently structured. Consequently, decisions in the initial design process are taken with a relatively high degree of uncertainty.

During code checking however, the application of rules and codes, using the knowledge and the abilities taught during training, is a process that can only be right or wrong. Of course this is only right in principle, as codes can sometimes be interpreted differently. Apart from that, structures can be out of range of anticipated objects for which the code has been made.
Whether a designer creates a more effective structure due to a better understanding of the material and uses an attitude in which he follows a good structured design process, anticipating the objective of the design question he is solving, is not a matter of true or false. This is a question of better or worse; of more or less effective, as illustrated in figure 1.

The consciously structured approach of a design question is a matter of quality. This means that attention for quality has to be present always in excess of specifications. Awareness of quality during the execution of a process prevents errors in specifying and presents better products with less effort.

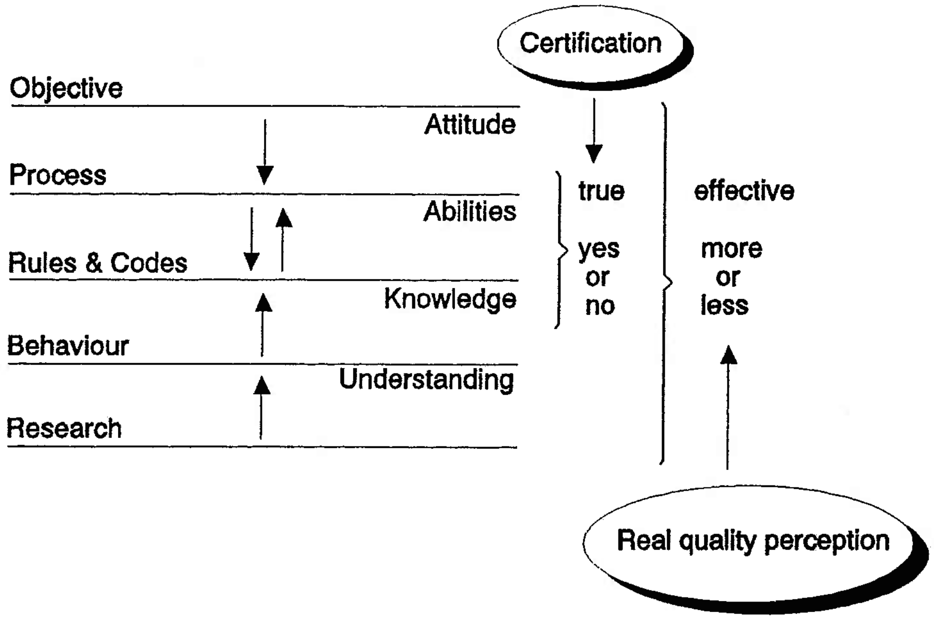


Fig. 1 Sources and their learning objectives

Another important reason not to use routine only, is the fact that everything changes, quite obviously in an accelerated way. Looking again to the objectives of the learning process and the underlying means, some examples of these changes can be given.

Changes in	**learning and society affecting the design**	
Objective	Environmental considerations Speed Request for integral approach Attention for labour conditions	
	Demand for quality assurance	**Attitude**
Process	Larger and more sophisticated computer programs	
	Less available experience Less technical feeling	**Abilities**
Rules & Codes	Ever thicker; Penetrating in everything International Codes (Eurocodes)	
	Ever harder to know everything required Experiments with databanks and AI systems	**Knowledge**
Behaviour	New materials New production techniques giving new details and shape	
	More difficult, because of attention for more aspects	**Understanding**
Research	More and Deeper Individually more narrow	

3. THE BASIC ELEMENTS IN AN INTEGRATED PROCESS:

PROJECT CHARACTERISTICS, CONTROL SYSTEMS, METHODOLOGY OF THE PROCESS AND SUPPORTING SYSTEMS

3.1 Design and construction, different from manufacturing

This chapter deals with the basic elements that are present in every design, design-construct or engineer-procure-construct-install (EPCI-Contract) job. It should be clear that not just the structural design or the structural analysis is part of this process. It involves the whole design in view of construction schedule, costs, technical possibilities and potential risks.

It should be realized that this is a process of generating and communicating information, of applying the right knowledge, of making decisions and of documenting. This process takes place within an organisation consisting of human beings, where every participant is supposed to have his own role. The process can be supported by all kinds of means facilitating communication such as telephone, fax, PC and CAD networks, PDI, EDI etc.

The process sketched above also involves planning of construction method and schedule. In the construction industry this is usually organized differently. Quite often the design is done by one party, the consultant and the architect, whereas construction is done by the contractor, conform drawings and specifications received in the tender documents. In the motorcar industry, design and preparation of construction is just one thing, carried out in one organisation, taking into account costs, technical possibilities of robots, materials and other aspects required for manufacturing.

The construction process itself is mainly a logistic process, meaning that the presence of sufficient construction materials, workers and equipment in the right place at the right moment is crucial for the actual construction. Of course information is important, but it is generally supposed to be present, supplied by a third party such as the consultant. Otherwise construction is supposedly impossible.

In view of the consequences of the characteristic difference in the organisation and control of design and construction, it is clear that in case resources are present, the construction process can be easily accelerated by merely increasing the supply of resources, whereas the design process requires a complete rethinking of the methodology before acceleration can actually take place.

Consequently, to illustrate the statements mentioned above one could say, "it is possible to build a house in one day, but it is impossible to plan to build a house in one day", the reason being that the actual construction is a logistic process and the planning of the method and schedule of construction is an information process requiring a specifically selected sequence of execution to deal with complexity, uncertainty and the hierarchy of all people involved.

3.2 The basic elements of a design process

The design contract

Figure 2 shows the essentials of a design task in terms of different activities to be performed. It is essential to realize that a design task ends with a report in any format. This may be a written report on paper, a floppy disk, a digital product or anything beyond or in between. In any way, it is information carried on a specific medium. The wish for generating the information required by a client is laid down in a contract.

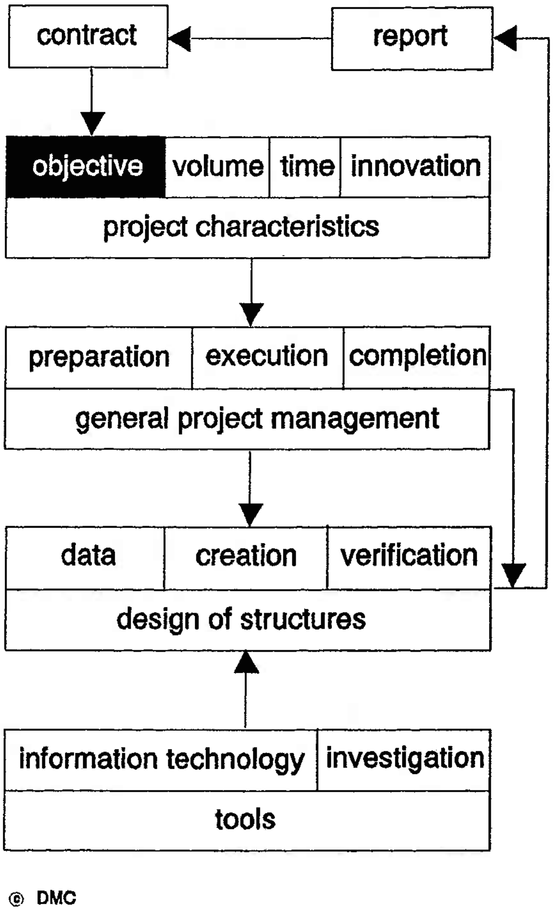


Fig. 2 Diagram showing the basic elements of a design process.

The design objective

The first quality aspect to be realized is the definition of the objective. Why does a client require a design report? Is it to have a vague idea of whether something is possible, or is it to have information for the construction site for actual construction. Both client and consultant need to realize this in order to have a fit for purpose job to be performed. The latter is precisely idea of the ISO 9001 Quality Assurance concept.

Further design characteristics

Other aspects that are considered to be characteristic of a project, are for example relative volume, time allowed for completion and the relative innovative character of the problem, the latter meaning: Is it just a new process, or does it also involve new means to create the new product? These project characteristics dictate the way the project is managed in practice and the emphasis in the methodology to be adopted when worked out. The consequence of the accuracy of the answers in the report and the acceptability of exposure to risks when conclusions of the report are taken for granted should be settled satisfactory when project characteristics are established and evaluated correctly.

Engineering management

A design project, as a process, should be controlled by a steering system, being the general project management. This involves a clear start with a well defined project team, having well defined tasks, responsibilities and authorizations, all together with a clear organisation.

When the project is started, a schedule of resources to be used in time, should be there to check whether the project runs on time, does not overrun costs and provides sufficient information in time.

The last set of management tools to concentrate on is the management of completion. Is all data found properly reported, is important data saved for use in the future, are all decisions properly documented in order to facilitate second opinion investigations and approvals.

Design methodology

The design itself should have a methodology which may vary for different project characteristics. In general it is characterized by a stage of data collection, creation of options and the verification of the selected solution.

In the stage of data collection, the functional requirements of the structure as well as the codes and specifications against which the design has to be checked are established and frozen. Then the creative process can start with the generation of possible alternatives. These have to be shaped, sized and further specified for the main materials to be used. From this some alternatives, say 3, have to be evaluated a little further on the basis of costs and functional prospectives. One solution can then be selected for further optimization and detailing.

It is essential for the rest of the process that this conceptual design is described in such a way that all sizes, the shape and the material specifications are explicitly documented. This serves reviewers, facilitates the judgement about later modifications and last but not least helps the designer to judge himself wether he has forgotten anything essential.

The verification, checking by model analysis whether the structure really fulfils the assumed functional requirements and the applicable codes, concludes the design process.

Computer programs

During the design process, tools have been used of which information technology products such as hardware and software are the most important ones.
Quality assessment using IT tools is most important. In order to be satisfied that the programs are sufficiently reliable, properly used and their results correctly interpreted, quality assurance for using a computer should address the following points.

Software

- Programs should show a record that they are sufficiently tested and therefore reliable.
- Programs should be documented in such a way that they can be used within the domain in which they are applicable.
- Programs should contain facilities, such as graphic controls, with which input errors are easily discovered by the user.

Problem

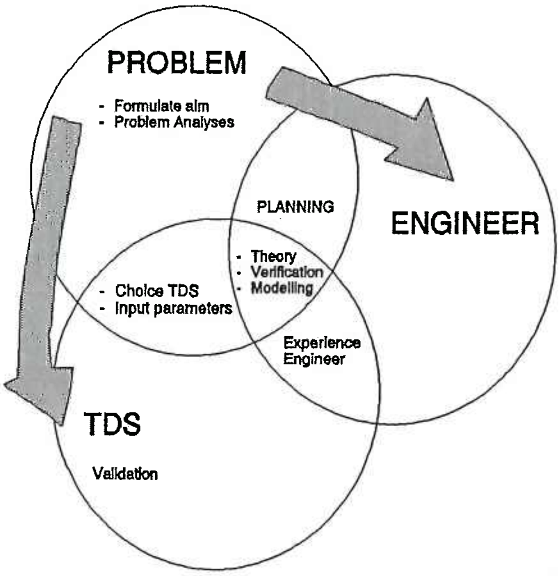
- It should be investigated first what the objective of a computer analysis is, as the kind of program used and the required accuracy of the answer are related to this goal. Finding the order of magnitude of forces, to select shapes and sizes, require different programs and accuracy then final code checking on load combinations.
- It should further be checked that data required for a specific program is available for input.

Designer

- Apart from finding a designer who can judge the problem, the designer should be authorized on the basis of experience to use a specific program.

- Last but not least, all three aspects come together, when it is required to check that the theory on which the computer program is based is valid for the problem, that the modelling is performed correctly and that some verification of the answer is carried out.

Quality Control and Technical Design Systems



=> Procedures in QA/QC Manual

Fig. 3 Scheme showing the points of attention for a computer analysis in relation to the different aspects

Summarizing what a QA system for a design task should involve it can be said that:

Quality Assurance in design should contain a careful analysis of the objective of the design, after which it should guarantee an execution according to a consciously selected methodology, with reliable tools in a well controlled way.

4. THE SLEIPNER ACCIDENT, ANALYZED AS A LESSON FOR QUALITY ASSURANCE

4.1 What happened

In the early morning of 23rd of August 1992 at 6.00 AM, the base structure of the Sleipner A oil production platform sank and imploded 15 minutes after a leak had caused an ingress of water of about 500 m^3 per minute. As the de-ballast capacity was only 2250 m^3 the superintendent decided to evacuate all 20 people on board, which was carried out successfully.

At the time of the accident the platform had been ballasted for testing the deck mating operation scheduled for later that week. It had a draft of 99 m in a fjord with a waterdepth of 200 m. Due to the implosion of the cells, the platform disintegrated into pieces with a maximum size of 20 m on the bottom. Consequently, no recovery of a wreck was possible and a close investigation of the debris covered by mud on the bottom was of hardly any use.

Nevertheless a cause of the accident was established quite soon after the incident. The crew had heard a heavy bang and observed ingress of water in cell D3 under one of the shafts. This concentrated investigations on the wall between cell T23 and cell C3. As shown in figure 4, in horizontal and vertical cross section and in detail, it can be seen that a wall of 550 mm thickness and 3500 mm span had to support a waterhead of 99 - 32 = 67 m, meaning that an average shearforce of 670 x 3.5/2 = 1173 kN/m had to be resisted by a wall of 550 mm thickness, therefore an average shearstress of 1173/550 = 2.13 N/mm^2 in a wall where no adequate shear reinforcement was present.

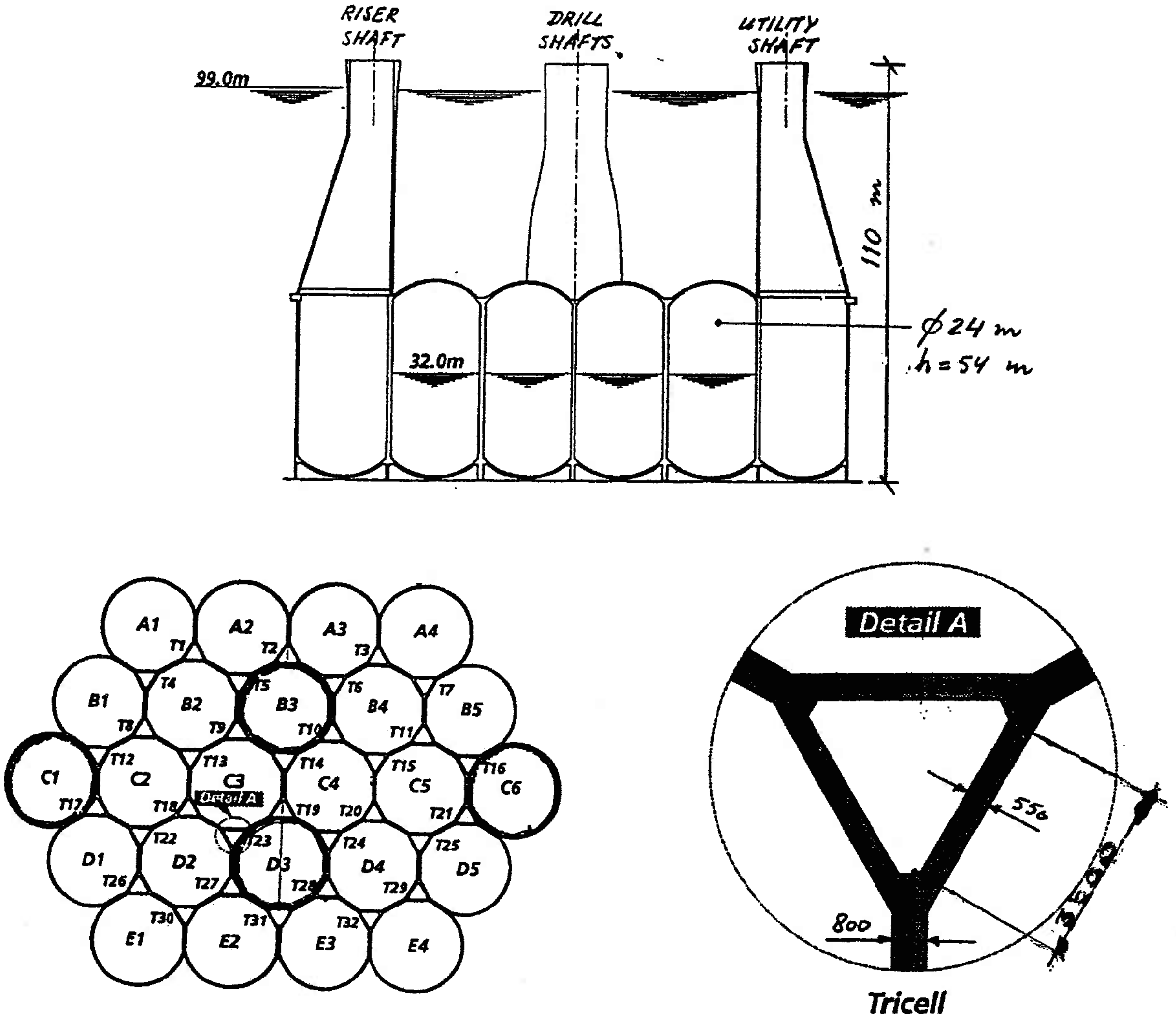


Fig. 4 Vertical and horizontal cross sections and detail of the Sleipner GBS

Although the real stress analysis is of course more complex, as bending and pressure forces also act on the cross-section, it is obvious that a weak point could be clearly detected in this slide rule type of analysis.
Later investigations, such as more detailed FEM analysis and even model tests, proved that this wall was bound to have failed under the loading that had occurred.

4.2 **How this could have been avoided**

4.2.1 The approach

Although the question of who did something wrong, who was responsible, who was liable, is of course very important to the financial aspects of the disaster. An answer to these questions is usually not of prime interest to the improvement of the art of design and engineering management.

Most publications after the incident discussed inadequate modelling and detailing during the detailed engineering stages of the job. Although this is of course correct, as laboratory experiments have confirmed, it would be disappointing if such accidents are caused by insufficient attention during detailed design only.
To improve observation of what happened, several mechanisms, which were not present at the time, can be distinguished which could have prevented the accident from happening.

In general, two approaches are possible. One is to prevent accidents by front end measures controlled by QA systems. A carefully applied methodology during the different design stages, including proper documentation, are a part of this.
The other means to decrease the damage by possible accidents is by back end measures, such as testing, recording of operations and building in alerts to warn for dangerous situations.

4.2.2 Material specification

Many smaller incidents on site and laboratory experiment on site have indicated that High Performance Concrete is a brittle material that fails in an explosive way when subject to forces causing cracking. This is due to the fact that the cement-fines matrix around the course aggregate is stronger than the aggregate itself. When this matrix fails, the crack continues through the aggregate. The only way to prevent this is by a proper three-dimensional minimum reinforcement that can absorb the tensile stresses in the structure in case the HPC concrete fails in tensile. This means that the material specification for areas with high tensile stresses, as is the case with high shear, the vicinity of prestressing anchors and areas under tensile forces should be properly reinforced. In case of the Sleipner platform this should have involved the application of a minimum amount of stirrups in the wall that failed. This would have prevented sudden failure and in the worst case heavy cracking would have occurred.

4.2.2 Sizing

As shown in 4.1 it is quite easy to find dimensions for the heaviest loadcase for the particular wall that failed. Such calculations would have shown that the wall could only have supported the load with shear reinforcement. This supports that it has to be considered to make and document small calculations to justify the dimensions selected for the concrete member sizes. Proper documentation of the sizing would have shown the weak spot in a review.

4.2.3 Shape

The bins of early NC Condeep type platforms were of a circular shape whereas the present ones are of a polygon type. Although the circular ones may have caused some geometry problems during construction, for formwork and detailing, the overall stress distribution was simpler and avoided the use of plates with heavy shear.The overall stress distribution was governed by membrane compression stresses. Platforms of the old type, as the Statfjord A, carry about the same deckload in deeper water with approximately the same amount of concrete yet only half the amount of reinforcement.
It must be said in general, that young engineers today do not pay much attention to a logic shape and start analyzing anything that is globally shaped and sized without much care. Anything can be analyzed with FEM, therefore the attitude seems to be "so what".

4.2.4 FEM analysis

The FEM model used as presented in figure 5 is obviously inadequate given the overstressing that occurred during the loadcase causing failure. Apart from that it can be questioned whether straight forward elastic FEM analysis in this way is the right way to detail reinforced concrete structures. For steel structures a stress analysis is sufficient and has to be completed with an analysis on elastic stability and fatigue. For reinforced concrete however, the analysis has to be followed by the detailing of reinforcement which is a complex task in case of offshore structures, as many load combinations from many loadcases have to be analyzed and absorbed. These loadcases, arriving from different wave directions, different waveheights, different wave steepnesses, different tide, different deckload configurations and different construction stages, leads to a voluminous stress accounting.
Sometimes automatic post-processors care for detailing of reinforcement, in which case it becomes quite impossible for the designers to get a feel for what loading or load combination causes which critical loadcase for detailing reinforcement.

Even in case of a correct FEM analysis it becomes questionable whether this type of analyses is sufficiently reliable to be the only means to check the integrity of a structure. Re-analysis done with other programs may be a way out, but careful sizing and shaping as mentioned before gives a more reliable check.

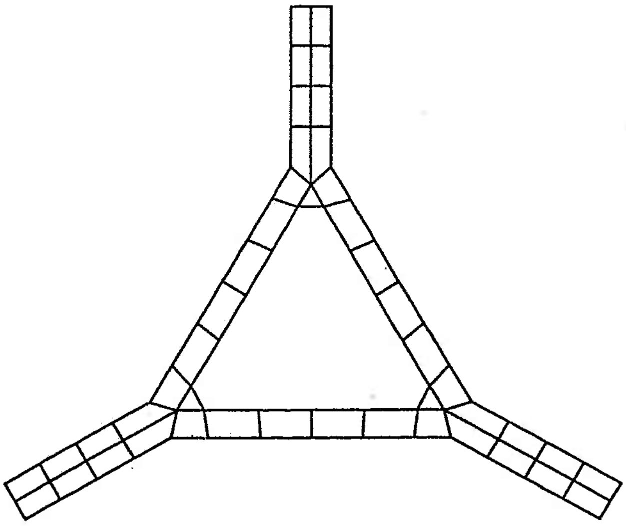


Fig. 5 The FEM model used in the global analysis model for Sleipner A

4.2.5 Detailing

The FEM analysis has obviously given some high tensile stresses there where the walls of the tricell join. For that reason, a so called T-Headed Bar, used for shear reinforcement in plates, consisting of a ϕ25 mm bar with 16 mm thick □ 70 mm plates welded on the ends, at @ 170 mm distance were placed as presented in figure 6. Figure 6 shows that these bars are too short and therefore ineffective. A laboratory test confirmed this pattern of failure.
It is obvious that the detailing was inadequate and not looked at by someone understanding the structural behaviour of concrete when loaded to failure. The T-Headed Bars should have been longer from side to side of the outer perimeter of the joint and as mentioned under 4.2.2, they should have been present all across the wall.

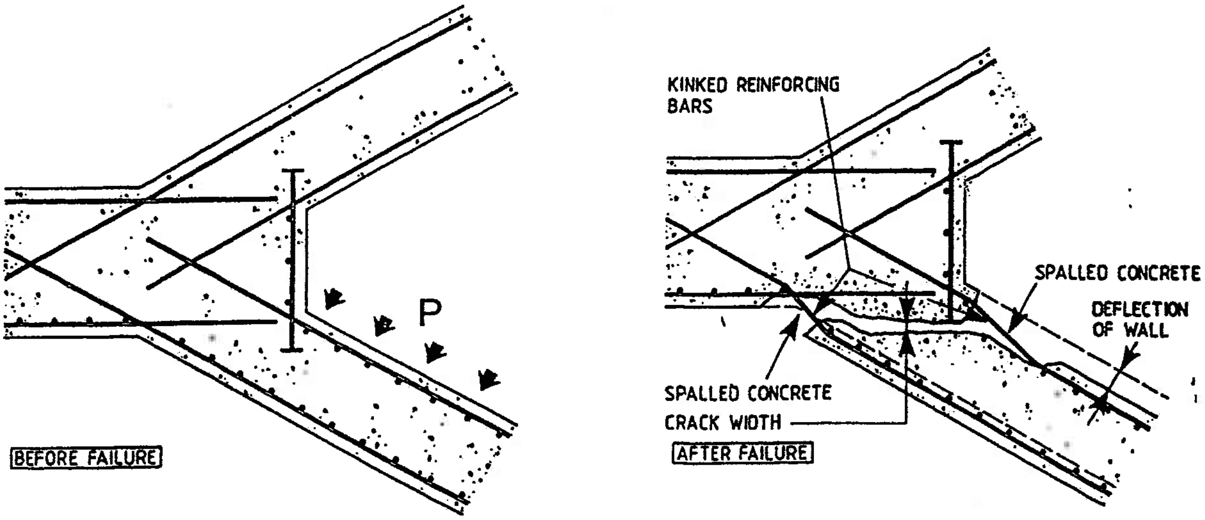


Fig. 6 Failure mode as assumed and proven in the laboratory

4.3 Conclusion

The different steps in the process of design and detailing as presented, offer a certain amount of redundancy to prevent disasters as occurred in case of the Sleipner A platform. It is therefore required to have a sound Quality Assurance system right from the beginning of the design work. If that is implemented and really used, accidents as with the Sleipner platform will only be incidents and will not become a trend.