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Durability, Defects and Repair of North Sea Structures

Durabilité, détérioration et réparation de plateformes en Mer du Nord

Dauerhaftigkeit, Schäden und Reparaturen von Tragwerken in der Nordsee

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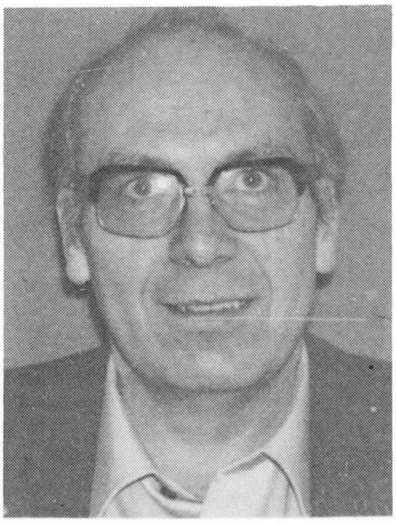

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SUMMARY

The paper gives a brief summary of the findings from the in-service inspections on North Sea offshore structures. Needs and methods for maintenance and repair are outlined. The causes of the observed deficiencies are discussed. Main issues for the steel structures are accidental impact and other unforeseen overloading. Other significant findings concern cracks and the cathodic protection systems. The concrete structures have performed well. A few localized structural deficiencies required attention. On some older platforms the mechanical systems gave some concern.

RÉSUMÉ

L'article résume les observations faites lors d'inspections de plateformes en service en Mer du Nord. Les exigences et les méthodes d'entretien et de réparation sont résumées et les causes des problèmes observés sont discutées. Les éléments saillants concernant les structures métalliques sont les chocs accidentels et autres conditions de surcharges non prévues. D'autres remarques d'importance s'adressent à la fissuration et aux systèmes de protection cathodique. Les structures en béton ont un bon comportement, sauf pour quelques défauts localisés qui exigent un soin particulier. Certaines plateformes plus anciennes ont connu des problèmes de systèmes mécaniques.

ZUSAMMENFASSUNG

Der Aufsatz gibt eine kurze Zusammenfassung der Ergebnisse der Betriebs-Inspektionen von Offshore-Tragwerken in der Nordsee. Bedarf und Methoden für Wartung und Reparatur werden beschrieben. Die Gründe für die gefundenen Mängel werden diskutiert. Die wichtigsten Probleme für Stahltragwerke sind Stossbelastungen und andere unvorhergesehene Überlastungen. Andere wichtige Erkenntnisse betreffen Risse und das kathodische Korrosionsschutzsystem. Die Betontragwerke erfüllen ihre Funktion gut. Wenige lokale Mängel der tragenden Bauteile erfordern Aufmerksamkeit. Bei einigen älteren Anlagen bestehen Probleme bei mechanischen Komponenten.

1. OFFSHORE STRUCTURES IN THE NORTH SEA

1.1 Number and types of structures

Since the first steel structures were installed in the shallow Southern North Sea in the sixties more than 100 steel jackets and altogether 20 concrete structures have been installed. The water depth record is held by the 216 m deep Gullfaks C platform installed the summer 1989.

Two main types of fixed structures are considered.

1) Steel jackets i.e. space frames built up of slender tubular members with piled foundations.

2) Concrete gravity base structures composed of a voluminous caisson base with 2-4 large diameter towers projecting up throught the water surface and supporting the deck. Other platforms consist of one large central shaft surrounded by a perforated wall.

This paper covers all 20 concrete structures, and about 30 steel platforms including all on the Norwegian Shelf. Smaller structures such as loading buoys and floating units are not covered.

1.2 Environmental exposure

The environmental exposure in the North Sea climate is characterized by large static and dynamic wind and wave loads, fatigue exposure and corrosivity. Typical wave heights with one month recurrance periode is in order of 20 m whereas the design wave (100 years recurrance periode) is about 30 m.

1.3 Materials and workmanship

Low carbon structural steels with yeld stress typically 360 MPa are specified for the steel structures. All essential welds are 100% X-ray tested. The concrete structures have concrete qualities in the range from C45 to C60.

1.4 In service inspection

The oil companies as well as the Governmental Authorities require all significant points of the platforms to be inspected on a yearly or four-yearly basis. In addition special surveys are made whenever found appropriate e.g. after possible damage. In service inspection of both steel and concrete structures are based on visual inspection. Steel structures are also subject to NDT inspection i.e. MPI, ultrasonics and potential measurement of the corrosion protection. The reliability and detectability of small deficiencies by the NDT methods under water has been questioned.

2. STEEL STRUCTURES

2.1 Cracks in welds

Cracks have been observed on a majority of the platforms investigated. The maximum length was 750 mm. In platforms where the cracks cannot be related to improper design or overloading, cracks were observed in 6-7% of the welds investigated. About half of these cracks were removed by grinding to a depth of 2-3 mm. Occationally much deeper grinding has been carried out.

Particular investigations have been made in dented areas and at burn marks. The crack frequency was much higher in these areas, but a majority of them was removed by grinding.

Cracks not removed by grinding have been kept under observation to see possible propagation. Cracks caused by loads inadequately designed for only, were found to propagate as expected for a fatigue crack. There are, however, cases where cracks turned up again after apparently successfull grinding removal.

Several crack cases required comprehensive repair work i.e. by welding, bracing removal, construction strengthening etc.

2.2 Dents and deformations

Dents were observed on the majority of steel platforms. In most cases they are accompanied with deflections of the member in question. Dent observations are evenly distributed over the heigth of the platforms.

As mentioned cracks are frequent in the dented zones. The cold working associated with the denting can result in surface brittleness. The irregular distorted geometry gives stress peaks which promote fatigue. There are cases where bracings have broken as the result of these mechanisms.

Where repairs were found necessary, the damaged members have been cut out and new sections have been introduced by welding and clamping. Dented struts have had their capacity in compression reestablished by filling the tubular member with grout.

Local strengthening has been accomplished by welding on doubler plates or by mechanical clamping fixed by bolts. Clamps grouted around the weakened structure is another popular repair method. In some cases stabilizing braces have been welded on to the deflected member to avoid further deflections. In other cases a paralell bracing have been welded to unload the damaged member.

The accomplishment of these operations under water, or even more complicated, in the splash zone is a difficult and expensive undertaking.

2.3 Corrosion

General corrosion is no major concern. Only a few platforms are found to be seriously attacked, and in limited areas only.

Pitting corrosion, on the other hand, is observed on the vast majority of platforms. Pitting 5 mm deep is not unusual. The extent and seriousness of the pitting vary significantly between platforms and between nodes. No particular elevation seems more exposed than others.

Most of the pitting seems initiated shortly after the platform installation, maybe before the necessary cathodic polarisation is established.

The cathodic protection systems seems rather vulnerable. Lost or loose anodes or other anode deficiencies have been observed on more than half the platforms.

Approximately half the platforms were also found to have too high electrochemical potential (i.e. more positive than -0.85 V to a silver electrode). On about one third of the platforms more anodes have had to be added after the installation. Metallic debris in electric contact with the platform increase the anode consumption. This kind of debris have had to be removed from all the platforms.

2.4 Sea floor erosion

Platforms installed on an erodable sea floor are normally designed assuming 10 ft seabed erosion. The platforms dealt with in this paper are mainly in water depths 70 m and more. Only one of these platforms experienced erosion exceeding the design assumption.

2.5 Marine growth

A majority of the platforms experienced a significant marine growth. The first platforms installed were not designed to resist the added hydrodynamic loads associated with the fouling and cleaning has been necessary. The design criteria introduced for later platforms seems to cover the growth observed in practice.

2.6 Conclusions, steel structures

A large portion of the significant structural findings concerned impacts from ships and dropped objects. Similar type of impact and overloading occurred during installation.

Another important reason for repair is static overload. In some cases the strengthening was necessary to cope with increased loads beyond the original design basis. In other cases the cause might be classified as design errors. Some more robustness to accidental impacts and other unforeseen loads might have been desirable.

Damages classified by "cracks" and "workmanship" cover a variety of different causes. A majority of these cases should probably have been avoided by better site supervision and control.

3. CONCRETE STRUCTURES

3.1 Leakages

Leakage through porous concrete, cold joints or encased pipes was only observed on some of the platforms constructed in the early seventies. Apart from the three cases mentioned below signs of leakage has only been observed by deposits and occasionally a humid surface. This always was a temporary problem and after a few months the seepage selfhealed. It is a general observation that cracks and porosities heal and seal by deposits ($CA\ CO_3$ and $Mg\ (OH)_2$) produced by reactions between the concrete and the sea water.

In one case the ingress of water was as large as $5m^3/h$. The ballast pumps could easily cope with this leakage rate. Without further precautions the leakage was observed to decrease with time and after three years the inner surface was completely dry.

Two minor leakages were sealed by injection with epoxy. A minor leakage through a burst plastic pipe was repaired by grout injection.

3.2 Foundation cracking

Cracks were observed in a cantilever wall supporting part of a foundation slab, presumebly caused by uneven soil reactions. The cracks were injected by epoxy and the surrounding sea floor covered by scour protection.

3.3 Precast formwork spalling

Some of the early platforms were fitted with a perforated breakwater wall. For convenient construction a precast concrete formwork was applied. On one platform this formwork spalled off in a limited area. The cover to the reinforcement was reduced more than formally acceptable. Repairs were done by replacing unsound concrete by cement mortar and covering the area with epoxy.

3.4 Impact damage

Five cases of significant ship impact have been reported.

None of them resulted in damage reducing the structural strength. Four impacts resulted in minor scratches in the concrete surface only, and no repairs were necessary.

One of the impacts caused through-cracking. A leakage of 5 litres/min was observed. This damage concerned one of the first platforms in the UK-waters. It was not designed to resist ship impact.

To avoid possible rebar corrosion the area was repaired by:

- epoxy injection of the cracks and cavities
- grouting removed unsound concrete
- epoxy coating internal and external surfaces.

Eight dropped object cases have justified subsequent structural investigations. Six investigations concluded no repair to be required. These concerned pipes of diameter up to 30".

A 36" spool piece of 10.5 t weight was dropped onto the caisson roof and punched through. The structure was found to be structurally sound and operation could continue without further measures. As the punched caisson was used as oil storage a repair was undertaken by grouting cement mortar into a prefabricated form filled with gravel.

A 36" drain caison of 20 t weight was dropped onto the caisson roof. The only consequence was some spalling of the concrete cover. Epoxy was injected under a formwork to restore the rebar cover formally required.

3.5 Seafloor erosion

One case of seafloor erosion has been observed. This concerned two voluminous concrete structures installed close to each other in relatively shallow water. The situation was stabilized by filling the eroded area with sand bags.

3.6 Conclusions, concrete structures

It is remarkable how well the concrete structures in themselves have performed in the hostile North Sea climate. No signs of material deterioration, rebar corrosion or other deficiencies have been observed.

A common feature of the findings on concrete structures is their local nature. The structural integrity of the platforms has never been jeopardized. Typical cases have been impacts from ships and dropped objects resulting in local cracking of the concrete.

Concrete platforms normally have comprensive mechanical systems for ballasting, water outlet, oil storage etc. On some of the early platforms these systems were not adequately designed. Material weakness and inadequate tightening of pipe penetrations have lead to a few leakages.

A general conclusion to be drawn is that the concrete structures required significantly lower expenditures for inspection, maintenance and repair than the steel platforms. The extent of the inspection tends to be reduced over the years as no findings are made under normal operating conditions.

TABLE 1

Reported repairs of North Sea Offshore Structures.

Repair, replacement and installation of new anodes, grinding of smaller cracks and marine fouling removal not included.

Causes	Steel structures	Concrete structures
Local foundation overload	-	1
Dropped objects	8	2
Ship impact	7	1
Workmanship	5	3
Abrasion by hanging objects	-	2
Precast formwork spalling	-	1
Static overload	8	-
Fatigue	3	-
Other cracks	7	-
Erosion	1	1
	39	11