Structural Safety Under Extreme Loads

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Extreme natural events, such as earthquakes or hurricanes, damage many structures both onshore and offshore around the world every year. In this document, three types of natural events are addressed to evaluate structural safety under these extreme loads.

Earthquake

Earthquake is the perceptible shaking of the surface of the Earth, due to the seismic waves from the sudden release energy in the Earth's crust. Earthquake can be catastrophic and devastating to both human lives and structural safety.

In this section we will talk about the basic Eurocode requirements for structures and two structural design aiming to enhance the earthquake resistance.

1. Eurocode 8: Design of structures for earthquake resistance
Written in the very first page, the objectives of seismic design is to, first, protect human live and second, limit the damage and the last, structures important for civil protection remain operational.

In terms of requirements in construction, these objectives indicates two levels of seismic design. The first one is **no-collapse requirement**. The structure shall be designed and constructed to withstand the design seismic action without local or global collapse, thus retaining its structural integrity and a residual load bearing capacity after the seismic event. This requirement is related to the protection of life under a rare event, even after the earthquake the structure may present substantial damages that may be economically unrecoverable, but it should be able to not collapse in the evacuation process or during aftershocks.

The second requirements is called **damage limitation requirement**. The structure should be designed and constructed to withstand a seismic action having a larger probability of occurrence than the design seismic action, without the occurrence of damage and the associated limitations of use. This requirements are made mainly for regions with frequent small magnitude earthquake or highly valued constructions such as, hospital, military base, and nuclear plant. After the earthquake, the structure should not have permanent deformations and its elements should retain its original strength and stiffness. Some damage to nonstructural elements is acceptable but they should not impose significant limitations of use and should be repairable economically.

2. Construction Design
In the sense of how to design a structure resist seismic loading, two ides are proposed. The first one is to enhance the structure integrity or in another word, the stiffness of the elements and the connections. And the other one is the relax the structure, which means that certain parts of the structure is relaxed, so as to dissipates the energy naturally instead of concentrate it.

In order to make the structure rigid, we can either use shear wall or cross-bracing. Shear walls are concrete walls with steel bars in them to reduce rocking movements and cross-bracing can reinforce walls with two steel beams. Shear wall is always designed to be parallel to the direction of shaking and the cross bracing normally is on the openings because the openings weakens the walls of the structure and is early distorted. Also, the cross-bracing can combined with shear walls, this means to assemble the cross-bracings in a way that it behaves like a shear wall.

And for relaxing the structure, two methods is also proposed, the first one is called foundation isolation (or base isolators) which absorb tremors of earthquakes. The building will not be directly connected to the foundation but "floating" on a system of bearings, springs or padded cylinders. When an earthquake hits, allow the foundation to move without moving the structure above it, in this way, the building's horizontal acceleration is reduced and undertake far less deformation and damage. Another one is called seismic colorseal which is simply made up of water-based, acrylic-infused expanding foam and factory-applied and cured silicone. This is normally applied at the connections of complicated structures, such as irregular shaped structures or extra-long structure shapes. Under the earthquake loading, the different parts of the structures might behave differently, and the seismic colorseal separate the structure into different parts so they can vibrate in their own frequency so as to avoid stress concentration on the corner or connection part.

Hurricane

Severe storm like hurricane is the culprit for structures in the ocean, particularly those floating structures used in oil and gas industry. Not only the industry might be disrupted due to the damaged facilities, but also there is the possibility of oil spill that can affect the environment and take years to recover. In 2005, it was particularly destructive season. It was the most active hurricane season in the recorded history. Hurricane Rita, for example, reached its peak intensity with maximum sustained wind of 285 km/h. Maximum wave height of 27 m was observed during Hurricane Rita. U.S. Bureau of Safety and Environmental Enforcement estimated that 3,050 out of the 4,000 total platforms in the Gulf of Mexico were exposed to hurricane conditions that year. A total of 115 offshore platforms were destroyed and another 52 platforms suffered serious damage. Chevron Typhoon platform, for example, lost its moorings and was found upside down 100 kilometers away from its secured location.

However, statistically, more than 95 percent of the offshore structures still stand strong after these record-breaking storms. Most of the destroyed or damaged structures were built prior to 1988 while most structures built to satisfy the post-1988 requirements survived. Offshore structures built since 1988 are designed to withstand the environment conditions up to Category 5 storms. The crucial design concept is that the structure need to maintain its integrity at all time. One damage may cause chain of actions and make things go out of control.

The structure must be able to withstand the gale force winds locally and globally. The local effects are related to the strength design of structure components while the global effects concern the total motion of the floating structure. Also, before evacuation, it is recommended to follow a high-level procedure for the tiedown of drilling packages and other equipment to prevent them from being knocked loose and damaging other part of the platform. Clamps with capability to withstand pressure as high as 13,000 megapascal are available in the market to secure major components in place under the hurricane wind conditions.

To address the wave threat from hurricane, regulations state clearly that airgap, which is the clearance between the highest wave crest and the lowest part of the platform deck, must be positive in all relevant sea conditions. That means the platform deck must position higher than the sea surface at all time to avoid impact load from wave slamming and to prevent extra loading from water that may flow and stay on the deck. The estimated height of hurricane-driven swell can reach up to 27 m. Recent fatal accident involving the COSLInnovator platform stationed in the North Sea emphasizes the importance of positive airgap. In December 2015, the platform was hit by a massive wave. Several windows on the lower deck were shattered since that part of the structure was not designed to resist horizontal wave loads, leading to the death of a worker onboard.

Vortex Induced Motions

Vortex Induced Motions are perturbations produced by alternating vortices generated in a steady current. When a uniform flow hits an obstacle such as the column of a platform, it passes around this obstacle generating vortices around. Due to instability generated by the turbulence, this vortices push the structure to one side, which in turn generates vortices in the opposite side that pushes the structure back again, generating thus an oscillating motion. Due to the nature of the fluid and the turbulence associated to the vortices, this phenomenon is highly dependent on the Reynolds number of the fluid. The nature of this phenomenon is not fully understand and there is no specific method to predict this behavior, so is typically overestimated in the design stage to prevent damages to floating structures.

Due to the nature of this motion, it only affects large dimension structures. This occurs because the oscillating motion has a frequency similar to the fundamental period of the structure. For smaller structures the frequency is higher than larger structures, so the motion generated by the vortices is more of a vibration, which is a completely different phenomenon studied under different conditions. The oscillating nature of the motion mainly provokes fatigue stresses in the anchoring elements, which need to be accounted for during the design stage. Anchoring elements such as cables are subjected to a tension/compression cycle due to the vortex motion, which helps development of fractures at lower stress values.

Due to the oscillating periods associated with the motion, the risk of resonance should be also accounted and studied during the design process. Since the motion is similar to the fundamental period of the floating platform, there is a risk of amplification of the motion which can lead to capsize of the platform if not treated with caution.

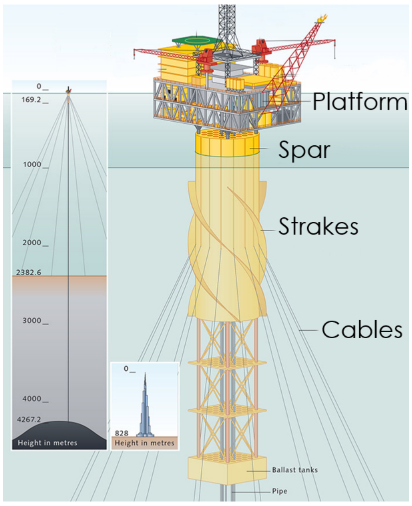

Figure 1: Diagram of a spar-type floating platform

Different methods are used to prevent the damage in the platforms. The most common approach modeling of platform during design and analysis process, either real life models or computational models, which help to see how the flow and the structure interact under controlled circumstances. Nowadays, this approach is the most reliable but also is very time consuming with an elevated cost, so it may not be appropriate for every study case. In practice, one of the most used methods to reduce Vortex Induced Motions is the addition of strakes, which are plates installed on the outside of the spar. Varying in shape but typically of a helicoidal shape, this plates are installed as a way to disrupt the vortices, which in turn reduces the oscillation. This method is one of the most extensively researched solutions, and studies prove that, even though it doesn't remove the problem completely, at least reduce the amplitude of the motion in about half the previous values. The risk of resonance should also by prevented during the design stages. The most common approaches point to modification of the fundamental period of the structure altering its mass or rigidity, as a way to differentiate the oscillating frequency from the fundamental one. Damping is also used as a way to prevent damages produced by the excessive movement caused by the vortices.

Conclusion

Continuous study and collaborations from relating industries will not only help us gain better understanding about these natural events but also the way onshore and offshore structures react to these extreme loads. The structural design innovations and safety have been improving and will continue to do so in the future.