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Building under Extreme Climatic Conditions

Construire dans des conditions climatiques extrêmes

Bauen unter extremen klimatischen Bedingungen

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SUMMARY

This introductory report summarises the climatic conditions to be found in five different environmentally classified areas of the world. In each area it outlines briefly the effect of these conditions on design philosophy, use of materials and execution of the construction activity. The paper concludes that future engineering for extreme conditions would benefit from quantifying the experience already gained and by publishing appropriate engineering standards.

RESUME

Ce rapport introductif résume les conditions climatiques présentes dans cinq régions du monde — classées selon leur environnement. Ces conditions ont des effets divers sur la conception du projet, l'emploi des matériaux et l'exécution de la construction. Il est nécessaire que les activités futures du génie civil dans des conditions extrêmes bénéficient des expériences déjà acquises ainsi que de la publication des normes dans ce domaine.

ZUSAMMENFASSUNG

Dieser Bericht fasst die klimatischen Verhältnisse zusammen, die in 5 verschiedenen Gegenden der Welt herrschen. Für jede Gegend wird aufgezeigt, welche Einwirkungen diese Verhältnisse auf Entwurfskonzept, Anwendung verschiedener Baumaterialien und Bauausführung haben. Der Vorschlag, dass eine qualitative Bestimmung der bis jetzt gewonnenen Erfahrung und die Veröffentlichung von zweckmässigen Normen dem Ingenieur beim Bauen unter extremen Bedingungen zugute kommen würden, beschliesst den Bericht.

Introduction

The motivation for undertaking construction projects in inhospitable areas of the world is frequently related to the exploitation of valuable natural resources such as minerals or hydrocarbons. Alternately such projects are required to provide essential communications or services to existing inhabited areas. Under these conditions the development of unusual and therefore expensive solutions are justified by either the economic return or social benefits that result. In recent years an increasing awareness has developed worldwide on two subjects directly related to the theme of this paper. One is the finite and in some cases quickly decreasing known reserves of essential natural resources and the need to conserve such materials by recycling or by eliminating unnecessary wastage whilst substitute materials are developed and additional sources are found by exploration. The second is the increasing world population and their expectations which eventually can only be accommodated inhabiting parts of the world which hitherto have remained underdevloped due to difficult environmental conditions. Unfortunately, the solutions to these two problems are frequently incompatible as to sustain life under extreme climatic conditions requires a greater input of materials and energy than would be involved in temperate climates.

The design or construction engineer who has been brought up and educated in a temperate climate has little experience of how to adapt to extreme climatic conditions. The engineering textbooks and codes of practice he is familiar with have been derived from many years of construction experience in his own or similar climate. He therefore needs to understand the philosophy upon which familiar rules and standard practices are based so that when faced with totally different climatic conditions he can modify his design premise, choice of materials and construction methods to provide a comparable optimum structural solution.

Historically engineers have proved that this adaption to totally different constraints can be successfully achieved. The evidence for this success can be witnessed in all parts of the world where engineering teams from every country with a well established engineering profession have assisted local inhabitants to undertake construction projects to the highest standards. The skills displayed on such projects also assist the country of origin in improving both trade and relations between the participating countries. The contribution that our profession makes to home economies and to the raising of living standards in client countries is rarely given appropriate recognition.

Extreme environmental conditions can be divided into five distinct types where special designs, materials or construction techniques are required to produce a structure which compares with what is achievable in temperate zones.

1. OFFSHORE ENVIRONMENT

Undeveloped mineral resources on, or beneath, the continental shelf and beyond have been identified for some time. The only industry so far to seriously venture offshore has been the oil industry in its search for new supplies of oil and gas. Initially, offshore development took place in shallow i.e., up to 50 m water depth and relatively sheltered locations such as the Persian Gulf, Gulf of Mexico, Lake Maracaibo and South East Asia. In the last 10 years development has moved into water depths up to 300 m in the U.S.A. and up to 200 m in the North Sea where environmental conditions are the most extreme encountered to date.

Design parameters in the North Sea are dominated by the effect of 100 year storm waves which can reach 30 m in height. The associated current speed is 1.5 m/sec and wind speed is 50 m/sec. In addition an offshore platform typically has to support a 20,000 tonnes pay load of drilling and production equipment. These storm conditions control the size of structural members of both jacket and deck structures even though allowable material stresses are increased by one third for extreme load cases. The joints of such structures however require careful fatigue investigation for during a single year 5 million waves varying from 1 m to 30 m wave height will pass through the structure. Stiffening or thickening of members at joints subjected to large wave action force components is often necessary.

The majority of offshore structures are built of steel and as offshore development has moved into colder climates such as the North Sea the selection of steel properties for these conditions has required careful investigation and judgement. Grade 50 steel is universally used as greater stress capacity would be ineffective due to fatigue considerations. Primary steel work is generally grade 50D (BS 4360) with improved properties for low temperature impact. For parts of the structure subject to tension normal to the steel plate such as a brace connection on a node then additional through thickness properties are required to prevent laminar tearing. As the structure has a potential life of up to 25 years it has to be adequately protected against corrosion. Sacrificial anodes sometimes with epoxy coal tar coatings are the most common solution.

The construction and installation of offshore structures is based on the philosophy of doing as much work on land as possible and in the North Sea to restrict offshore construction to the summer weather window from May to September. The size of land built components is only limited by the capacity of the offshore construction equipment available for the installation. Jackets have been traditionally transported to the offshore location by barge but with the early deep water platforms the capacity of existing barges was insufficient and self floating designs were evolved or as on the Forties field temporary floatation rafts were used. More recently larger launch barges have become available and designs up to 25,000 tonnes can now be accomodated. The deck structure is constructed in segments which are lifted by crane barges and set on top of the jacket after it has been piled to the seabed. The equipment is then installed in modular pieces on top of the deck structure. The current lifting capacity of offshore cranes is 3000 tonnes and the sea state conditions for such operations have been extended significantly by the new semi-submersible crane barges. A recent development to further reduce the installation and commissioning of the deck structure and modules is the concept of installing offshore a complete deck including equipment directly onto the jacket substructure. Part of this concept has already been used by many of the concrete offshore platforms where the buoyancy of the storage caissons of the structure allow a major percentage of the deck pay load to be installed inshore in deep sheltered water.

2. HIGH RAINFALL AND HIGH TEMPERATURES

In the tropics and semi-tropics temperatures vary from 20^o to 45^oC and the annual rainfall varies from 200 to 400 cm per year with rainy season peaks of 75 cm per month and 7 cm per hour. The average humidity is 80 percent and although wind speeds are generally low speeds of 65 m/sec can occur during typhoons.

A major design problem is accomodating material temperature changes of 60^oC by allowing sufficient movement at expansion joints. Differential temperatures are equally important as the resulting curvature will produce complex support reactions in an indeterminate structure. The rapidity of temperature changes as the sun sets or a tropical storm approaches can produce visible and audible motion as observed at the supports of a major steel box girder bridge in South America. Adequate drainage is essential to avoid foundation undermining and slope erosion during peak run offs.

On concrete structures reinforcement cover of 5 cm is required to avoid spalling due to corrosion of the reinforcement. Exposed steelwork requires regular painting and partly embedded steel should be galvanized. All materials are subjected to biological attack which quickly disfigure their surface although the structural properties may not be affected. Frequently local materials in particular hard woods have excellent durability. For example, in South America all temporary supporting members during building construction are timber due to the scarcity of steel scaffold.

Construction under these conditions can be extremely difficult due to simple problems like materials too hot to physically handle or more serious the presence of disease organisms. The availability of local construction plant may be limited and specialised skills such as welding among the local labour force may be non-existent.

3. HIGH RAINFALL AND LOW TEMPERATURES

These conditions occur in areas where continual wet snow occurs in the artic and subartic. Temperatures can vary between extremes of -70° to +40°C and remain below -45°C for 8 weeks at a time. Wind speeds reach a maximum of 45 m/s in the subartic and only 18 m/s in the artic. In spring and autumn fog and poor visibility are prevalent and during November, December and January there is no sunlight and minimal twilight.

Permafrost can extend up to 600 m below the surface and of course presents an excellent foundation providing the structure is thoroughly insulated from the ground to avoid disturbing the natural thermal equilibrium. Continuous foundations should be avoided and all loads should be carried on footings or piles extending down at least twice the summer thawing depth. The use of separated foundations also assists the structure in accomodating the large temperature movements which occur.

Construction materials have to withstand the continuous presence of moisture and the seasonal freezing thawing cycles. Concrete can be successfully used provided freezing is avoided during setting by using a combination of rapid hardening cement and heated aggregates and/or water and leaving formwork in place until a strength of 10 N/mm^2 is achieved. Steam heating during curing is beneficial as strength only develops slowly at low temperatures. The supply of water is a major problem as to melt snow requires large quantities of energy. The most dependable sources are deep lakes and rivers with water below the maximum freezing depth.

All the construction materials apart from aggregates have to be imported to the construction site. In Alaska for example material can only be brought in by sea during August and September and for the rest of the year air transport is the most reliable although overland freighting using tractors and sledges is possible. The output of construction workers lowers once the temperature falls below -30°C and construction equipment has to be modified to operate below -50°C.

4. LOW RAINFALL AND HIGH TEMPERATURES

Desert conditions exist in the western areas of North and South America, the Sahara, Arabia, Iran, South Central U.S.S.R., Mongolia, North Central China and Central Australia. They are characterised by temperatures varying daily from 15°C to 50°C and surface temperatures reaching 80°C. Rainfall is less than 25 cm per year which occurs in less than 30 days producing extremely low humidity. Dust storms frequently occur at speeds up to 10 m/sec.

Design considerations are mainly concerned with minimising the effects of heat particularly for buildings where thick walls and insulation with minimum window areas can utilise the relatively cool nights to reduce artificial cooling during the day. Foundations are generally simple due to well compacted sand layers but attention must be given to protecting them from undermining during wind storms by placing them deeper than usual. Large scale expansion of materials should be considered in detailing joints to avoid penetration of airborn dust.

Materials are subject to heat-aging resulting in premature loss of properties. Sand erosion can damage glass and plastic components and can remove protective coatings which is further aggravated by ultraviolet radiation. Steel lasts well provided it is coated with highly reflective paint as little corrosion takes place. Concrete of high quality can be produced by making sure the water and aggregate sources are uncontaminated and cool. Water curing should be used for a minimum of 24 hours to avoid surface cracking or plastic shrinkage cracks. Water supply is a major problem with sources being limited to wells, diversions from nearby streams or rivers on higher ground or from underground tunnels. Locally produced stone or bricks may sometimes be available and reduce the quantity of imported materials.

Construction in this climate has its difficulties for example, mechanical equipment requires carefully sealed high temperature lubrication systems. Personal discomfort may result from insects and night and early morning shifts should be used to minimise loss of worker efficiency. Western clothing and local clothing styles will help acclimation of personnel by increasing the loss of excess body heat.

5. LOW RAINFALL AND LOW TEMPERATURES

These conditions are found in the summerless polar ice caps of the Artic and Antartic and in Greenland. Compacted ice thickness in these regions can vary from a few metres up to 3000 m with dry powdery snow constantly present. Wind speeds can reach 90 m/sec and visibility can drop to 3 m particularly with fog in coastal areas. Temperatures can fall as low -90°C and may average -70°C with almost no rainfall.

Building design requires imaginative solutions and it is essential that all structures should be interconnected. Surface construction can be achieved using prefabricated components but requires extensive insulation and will continually attract snow drifts. Under surface construction within the ice cap has found to be more efficient as the temperature remains constant at -8°C and the ice is structurally sound for tunnelling without supports. Snow and ice can be used as a construction material for after mechanical compaction it can replace concrete in no-thaw areas. The disposal of waste material and polluted air from buildings requires careful consideration to avoid contaminating the area of inhabitation. Water supply is only available by melting the ice or by distillation of salt water.

Construction is limited to a period of 60 to 120 days i.e., November to January in Antartica and June to September in Greenland. During these periods a 24 hour working day is possible provided material delivery is correspondingly scheduled. Outside these periods the combination of darkness, wind and blown snow make outside work highly inefficient. Land equipment for these regions has only been partly successful with four track vehicles superior to two track vehicles where the crossing of crevasses is a problem. Power generation from imported fuel is expensive with up to 80% of the cost required for transportation. Nuclear power plants have been operating successfully in Alaska, Greenland and the Antartic but the waste products have to be returned in containers for disposal.

CONCLUSIONS

Construction problems in areas of adverse climatic conditions are now being overcome through the development of environmental engineering. This is achieving acceptable living and working conditions despite the extreme weather or terrain naturally present. Experience of designing for and building in these remote areas is now considerable and will help in finding improved solutions for the future.

The conditions outlined previously can occur temporarily in temperate zones and when they do normal construction has to be suspended or revised construction methods adopted subject to satisfying the original design criteria. In temperate areas of the world low temperature weather conditions occur in mountainous regions resulting in limited construction periods and compliance with extreme climatic design and material constraints. Occasionally it is necessary to develop design codes for specialised structures subject to unique environmental forces as those previously described for offshore structures. An example is the recent work in the U.K. to produce a new code of loading for the design of tower structures up to 300 m tall. The code is intended to be applicable worldwide although specific meteorological data is only given for the U.K.

As development in extreme climatic regions becomes more commonplace then rationalisation of design and construction methods will occur and appropriate engineering standards will be published. The engineering development for the Alaskan oil fields and pipeline should enable detailed design codes for this region to be produced from the experience of the oil companies, their designers and their contractors. It is to be hoped that the detailed case studies to be written for this congress will also assist in promoting a wider knowledge of the solutions which have already been achieved.

REFERENCE

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