1.054/1.541 Mechanics and Design of Concrete Structures (3-0-9)

Homework #1

Assigned: Thursday, February 12, 2004 **Due:** Tuesday, February 24, 2004

Design of a Concrete Gravity Platform

This problem is about failure criteria for concrete in a variety of stress states. An application considered in this problem is the concrete gravity platform (offshore structure). A brief introduction is first presented followed by questions on the behavior of concrete in this application.

Introduction

A concrete gravity platform is one that is placed on the seabed, and by its own weight, is capable of withstanding the environmental forces (wind and waves) it may be exposed to during its lifetime. Gravity-type concrete platforms are used for oil-drilling purpose in the oil industry. They are used when the soil/rock of the seabed is hard and relevant for supporting them since they rest directly on the ocean floor without pile foundation. Concrete platforms are larger and heavier than steel platforms. Although there are various designs of a concrete gravity platform, the base part is usually made of reinforced concrete and consisted of huge sub sea concrete tanks. These tanks are used for the storage of crude oil. For example, the base of a concrete gravity platform built for Mobil Oil in the North Sea consists of 19 hollow concrete cylinders of 2 ft wall thickness, 66 ft inner diameter, and 164 ft height. The cylindrical concrete storage tanks of the base are built to such a height that when the dock is flooded the base has sufficient freeboard to float on its own buoyancy. The base is then towed out into the deep-water site and the tanks are flooded, causing the base to sink to the seabed.

The platform rests on several (usually three or four) taller, tapered concrete legs (columns), which rest on several of the tanks. These columns can rise up to 300 ft above the top of the tanks. Finally the steel superstructure is placed on top of the completed concrete substructure. Sometimes grout is pumped beneath the bottom of the tanks to provide a firmer foundation. The platform is heavy enough to remain stable without pile foundation when subject to environmental forces.

Questions

1. Consider the base of the concrete gravity platform as a cylinder model. How deep could the open, flooded cylinders go before being crushed by the water pressure? Assume f_c' to be 5000 psi (lb/in^2) and ignore the end conditions of the cylinder and the contribution of reinforced steels. Use constant gravity weight for seawater[1]. Consider the tanks as open-ended tubes to simplify the problem.

2. Scrambling to be the first to tap the oil reservoirs in Siberia, Exxon hires 20 M.I.T. graduate students to design the base of a platform that is to be constructed in a 1700-ft

deep fresh water lake[2]. The tanks are to have the same dimensions as the Mobil tanks described above with f_c' to be 5000 psi. Apply appropriate idealizing assumptions and use a biaxial state of stress theory to compute how much platform each tank (tube) can support with a factor of safety (F.S.) of 3. Ignore stability problem (buckling) and consider only the through-the-wall section under the hydrostatic water pressure and the weight of tank and water above it.

3. Once the platform is complete and operational, the tanks are used to store crude oil. The Exxon engineers have told you that the platform weighs 500,000 tons to be supported on three tanks (tubes). Use a triaxial failure theory to compute the required compressive strength of the concrete to support the platform, with a factor of safety of 4. Consider hydrostatic pressure from seawater and the difference in density of fresh water and crude oil. Use 0.85 as the specific gravity[3] for crude oil. Do you think this compressive strength of concrete is manufacturable in Siberia? Please note the failure criterion you used and explain the reason why you use it.
   This question examines the concrete under triaxial stress. There will be three stresses acting on the concrete: σ_1, the pressure in radius direction, σ_2, the pressure in vertical direction, and σ_3, the hoops stress caused by the differences in the density of sea water and the density of crude oil. Use the following definition of hoop stress for convenience,

   $$\sigma_{\mathrm{h}} = \frac{p \cdot r}{t}$$

   where σ_{h} = hoop stress,
   p = difference in hydrostatic pressure,
   r = radius of cylinder,
   t = thickness of cylinder wall.

[1] Specific weight for fresh water at 60F is 62.4 lb/ft^3 (9.8 kN/ m^3), for seawater at 60F is 64 lb/ft^3 (10.1 kN/ m^3),
[2] Fresh water lakes could be as deep as 1932 ft, which is the record in the U.S. (Crater Lake, Oregon).
[3] Specific gravity is dimensionless defined as the ratio of density of the material to the density a specific temperature.

Note: In solving this problem, use your knowledge of concrete behavior in multiaxial loading. Make appropriate assumptions with respect to uniaxial, biaxial, and triaxial failure criteria. Note sources you may have used.