EARTHQUAKE ENGINEERING BEHAVIOR OF GRAVING DRYDOCKS

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SUMMARY

This paper presents a state-of-the-art analysis of the behavior of a graving drydock under the presence of earthquake forces. It also examines potential dangers from ships resting on the docks, and falling off the supporting blocks, blocking arrangements and design ways and criteria of design for safe use.

INTRODUCTION

The earthquake engineering behavior of graving drydocks plays an important role not as much us from the point of public safety, as for that of an economic construction. Unnecessary costs on earthquake protection could be very costly, but on the other hand very costly damage could result if it is shaken by a strong earthquake and has inadequate protection.

REVIEW OF SEISMIC EFFECTS

Earthquakes present two kinds of danger to graving or gravity type drydocks.

1. From horizontal ground accelerations the ship may slide or rotate on it supporting blocks or in case of unstable blocks, collapse of the blocks could occur, with result of serious damage to both the ship and dock.

2. From vertical accelerations, which will increase the gravity forces on the ship and blocks, with collapse as a possible result again. Another potential danger is the lift-off of the ship from one row of blocks, with result a transfer of load to the other rows of blocks which most probably were not designed to withstand the additional load.

Friction forces between the ship and blocks and between blocks and dock floor are in most cases great enough, so that sliding is unlikely, and shoring, further reduces the probability.

Where sliding occurs a minimum of 6 feet of clear space should be provided between each side of the ship and dock walls. (Ref. 1)

(1) "MODERNIZED BLOCKING FOR DRYDOCK SHIPS" Crandall Drydock Company Engineers, Cambridge Mass. 02142

The ship can be idealized as a lumped mass standing on elastic springs, (The blocks), which may oscillate transversely about its base at some natural frequency, which is a function of the ship's mass, polar moment, the center of gravity, and of the height, area, and elasticity of the blocks.

IMPORTANT EARTHQUAKE CHARACTERISTICS FOR SHIP STABILITY

Earthquakes manifest themselves in a series of shock waves of varying frequencies and amplitudes. If there is significant energy in the frequency band which coincides with the natural frequency of the ship block system, then the acceleration acting through the center of gravity of the ship may be considerably greater than the base ground acceleration.

The other hazard, the one of vertical ground acceleration may approach the magnitude of the horizontal but is generally less. The effect of vertical motion is to increase the gravity loads above those that the blocking and ship hull are normally subjected. Since design blocking pressures are generally low and the duration of loading is short, the blocks can take this brief overload so, that vertical accelerations are of less importance than the accompanying horizontal accelerations.

Adequate bearing for the ship hull and column stability of the blocks should be assured, however; and ship hull strength must be considered.

Maximum theoretical expected ground accelerations for a specific site is arrived at, by considering its distance from known geological faults and assuming, based on probabilistic, historical and geological data, the maximum intensity of an earthquake expected to occur at each fault.

For example, a wild quake at a fault close to a site could result in greater acceleration at the site than those due to a severe quake at a fault further away. (Ref. II)

Because a gravity dock is integrated within the ground, it is assumed to move with the ground, and thus the ship-dock system is subjected to a base shear equal to the mass of the ship and blocks times the appropriate ground acceleration. The effects of horizontal accelerations on the gravity-dock itself are not yet considered and the dock floor is in fact assumed rigid and in tact.

The ship-block system, as mentioned previously is represented as a mass-serving system that would oscillate at a natural frequency. In

(II) "EARTHQUAKE DESIGN CRITERIA" P. Jennings, G. Housner
California Institute of Technology, Pasadena, California 91125

a case of a transverse rotational frequency mode, the ship rocks about its keel block and the bilge blocks act as springs with their stiffness depending on the depth of the wood, the area of contact and the elastic modulus.

As this motion becomes more dynamic eventually the ship will lift off one row of blocks throwing an increased bilge load to other row of blocks which for a time will be carrying all the weight. At that time we have a change of the characteristics of system which can be accounted through by taking a longer natural period of motion.

In order to estimate the response of the system to seismic loadings as amplified by the resonance effect, a design spectrum should be composed. This spectrum indicates the maximum accelerations and displacements that should be anticipated (for a system of a range of periods and dumping values) for a base ground acceleration of .1g which then can be scaled to other values of ground acceleration. A different approach to obtain system response is by a computer aided dynamic analysis which combines actual earthquake data with the system (block-ship) characteristics and produces the consequent accelerations and motion felt by the system.

The above discussion on ground acceleration is of course of theoretical probable maximum. A lower design value can be assumed based on the probability of occurrence of an earthquake of a given magnitude at a given site within some predetermined period of time.

Corresponding to present U.S. Navy standards a drydocking facility is a major capital investment and should be subjected to a detailed dynamic analysis of seismic probability effects according with the principals of mechanics. For earthquake zones 3 and 4 the drydock shall be designed to resist the forces of an earthquake with an acceleration equivalent to an earthquake having a 20 percent probability of exceedance in 50 years, but not less than 0.12g. Another way to iterate this is that there is a 1/50 or a 2% chance of an earthquake occurring at given year that would exceed 0.2g. Under these circumstances a navy design standard of 0.2g is not unreasonable. It can be shown though that even moderate earthquakes in a range of magnitudes of 0.3 to 0.5 could cause a blocked ship of lift off one row of bilge blocks with an amplified ground acceleration. (Ref III)

For most ships the bilge blocks should and will be able to take an overload due to this effect for accelerations up to 0.1g.

On the 0.2g level extra measures should be taken to assure stability of the blocks on both longitudinal and transverse directions

(III) "GRAYVING DRYDOCKS" Naval Facilities Engineering Command, Washington, D.C.

and stability of columns of bilge blocks. For ground accelerations in the 0.3g and up to 0.5 precautions should be taken to prevent the ship from lifting off the blocks.

For accelerations of 0.5g and above it seems that there is no other alternative except by isolating the ship from the dock by use of a low friction system. A proposed one is an elastic bearing system already in use for seismic design of bridges and building overseas and lately introduced in the United States. (Ref. IV) At the 0.5g or more accelerations it should be noted that another potential danger is rupture of the walls and floors of the basin, thus leaving the ship totally exposed to damage independent of blocking failures, but this is a subject that is of no concern of this paper at this time.

DESIGN EXAMPLE

This example examines, two classes of naval vessels: the YTB-216 (Tug Boat) and CGN-g (Fast Cruiser) in Block Arrangement and stability when resting in a gravity dock which is hit by an earthquake. The YTB was chosen for shape and small displacement whereas the CGN-g was chosen for hull characteristics (thin) and moderate displacement.

NOMENCLATURE

Ip = Polar moment of inertia of ship about its K.G. ($K\text{-}Ft^2$)
P = Horizontal load to give (PH) minute moment in FT-KIPS,
C = Percent of weight on keel blocks
W = Ship displacement (LT)
B = Center to center distance of Bilge Blocks (Ft)
H = Height of ship K.G. above base of keel blocks (Ft)
E = Elastic modulus of wood
A = Area of bilge blocks one side = $\frac{(1-c)}{2}\frac{W}{fc}$ (in^2)
fc = Stress on blocks (Ksi)
KG = Center of gravity of ship above keel.
Az = Effective area of contact of 1 bilge block. (In^2)
Sp = Proportional limit of side block cap. Lb/In^2
Ms = Seismic overturning moment (Ft-Lb)
N_z = Required number of bilge blocks per side to resist overturning moment M_s
g = Earthquake ground acceleration

DESIGN ASSUMPTIONS

1. Ship does not slide on blocks
2. Floor of basin is rigidly fixed to firm ground
3. Modulus of compressibility remains in the elastic range
4. Bilge block area is constant for full height of timber

(IV) "THE ALEXISISMON" Dr. N. Ikonomoy, Patras Polyetechnic Institute, Patras, Greece

YTB-215 (Vessel Data)

W = 36g LT
KG = 10 Ft
A_2 = 672 in
S_p = 800 Lb/In^2 (Douglas Fir)

For 0.2g (Ground Acceleration)

Ms = (0.2) (W) (K.G.) (2240 Lb/Lt)
= (0.2) (369 Lt) (10 Ft) (2240 Lb/Lt)
= 1,653,120 Ft-Lb

$$N2 = \frac{Ms}{A_2\ Sp\ Bl} = \frac{1{,}653{,}120\ \text{Ft-Lb}}{(672\ \text{in})\ (800\ \text{Lb/In}^2)\ (10\ \text{Ft})} = .30$$

Use 1 Block Per Side

For 0.5g

Ms = (.5) (36g Lt) (10 Ft) (2240 Lb/Lt)
= 4,132,800 Ft-Lb

$$N2 = \frac{4{,}132{,}800}{(672)\ (800)\ (10)} = .77$$

Use 1 block per side.

From the above calculations for YTB-216 we can see that for small displacement ships, blocking could be minimal and still adequate to withstand moderate earthquakes.

CGN - 9

W = 14,000 Lt
KG = 32 Ft.
Az = 672 in.
Sp = 800 Lb/In^2 (Douglas Fir) (6 Ft. High Blocks)
B = 30 Ft.
H = Ship Height = 46 Ft.
Bi = Ship Beam = 72 Ft.

For 0.2g

Ms = (.2) (14,000 Lt) (32) (2240 Lb/Lt) =
= 200,704,000 Lb-Ft.

$$Nz = \frac{200{,}704{,}000}{(672)\ (800)\ (30)} = 12.5$$

Use 13 Blocks Per Side

For 0.5g

$$Ms = (.5)\ (140{,}000\ Lt)\ (32)\ (2240) = 501{,}760{,}000$$

$$Nz = \frac{501{,}760{,}000}{(672)\ (800)\ (30)} = 31.11$$

Use 32 Blocks Per Side

From the above calculations we see that for ships with moderate displacements it is required double number of blocks (and even shoring) for moderate earthquakes. In general it can be shown that lift-off will occur in any ship where:

$$PH \geq \frac{1-c}{2}\ (W)\ (B)$$

which means that at that time one row of blocks had twice its original load.

It can also be shown that the ship overturns

when $PH > (B/2)\ W$ and that
at $P > .5W$ ship may slide off the blocks
or $P < .5W$ force on ship may be amplified by harmonics.

CONCLUSIONS

It is the opinion of th author that graving or gravity type drydocks should be treated as critical facilities (in earthquake design) as they represent a very costly damage potential in both capital investment and life. They should be designed to a detailed dynamic analysis according with well established and accepted principals of seismic design with emphasis given in:

1. Site or vicinity of Drydock
2. Ship handling capacity of Drydock
3. Blocking and shoring arrangements for ship stability.

A future study should be made on base-isolation systems to be used when handling large displacement ships and structural stability of the basin walls and floors under the presence of earthquake forces.

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