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YUCCA MOUNTAIN PROJECT

ASSESSMENT OF EFFECTS OF AIRCRAFT IMPACT

ON

CATEGORY 1 STRUCTURES

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1. INTRODUCTION

The September 11, 2001, terrorist attacks have drawn attention to the possibility of such attacks on important targets. The Yucca Mountain Repository is such an important facility and potential terrorist attacks should be considered in design (Ref. 1). This report presents an initial assessment of potential consequences of such a terrorist attack on one of the facility buildings. The structure selected for this study is the Dry Transfer Facility (DTF). The report addresses impact of Design Basis Threat (DBT), which is a airplane, on the DTF and estimates its possible effects.

This is a qualitative look at the issue for initial assessment of the effects of the postulated event. The outcome is expected to help define the facility design criteria and layout parameters to minimize adverse effects of such events.

2. ASSUMPTIONS

Aircraft impact is a complex problem. It involves large quantities of energy dissipation in a dynamic environment, nonlinear response of both the aircraft and the target structure, and local failure of elements in terms of yielding and crushing. Therefore, many simplifying assumptions must be made in order to arrive at a reasonable solution. The following assumptions/criteria will be used to evaluate the structural damage to the Yucca Mountain Dry Transfer Facility due to the defined DOE DBT for aircraft crash.

- The aircraft to be considered is a
- The aircraft impact speed is given as This speed is unrealistically and the maximum speed near the ground surface will be about according to the manufacturer's data. However, the study will address both aircraft speeds.
- The body of an aircraft damage; it
- The damaging components are the and the as observed at the WTC attacks. Therefore, impact of these two components will be addressed in this report.
- The and the are assumed to impact the structure simultaneously. The is at the and the are separated by
- The other damaging element is the However, this study will not address the effects of

- Impact of aircraft on the walls of the structure is conservatively assumed to be perpendicular to the walls.
- Impact of aircraft on the is less likely and is expected to be at a small angle with the horizontal. Consequently, effects of impact on the is considered to be enveloped by the consequences of impact on the , provided that concrete thickness is at least equal to one-half the thickness.
- Concrete scabbing (ejection of pieces of concrete from the back side) . cause unacceptable damage to casks and waste packages due to the small sizes of scabbed pieces at much lesser speeds relative to the . Therefore, thickness does not control the design.
- Multiple concrete component structures (i.e , in the path) are available to mitigate the effects of impact.
- Available generic information to characterize the damage states in concrete structures due to high energy , impacts are applicable.
- Concrete design strength, f_c', is

3. AIRCRAFT GENERATED MISSILES

Two types of , associated with have been identified in an attachment to Ref. 2. These are:

- in diameter, at with distance between
- diameter, at), at between

Ref. 2 states that the can be treated as a However, this assumption would be too conservative since the consists of concentric shells and is far from being a The diameter is and the length is and the diameter towards the end. For the purposes of determining an equivalent shell, the maximum diameter and two-thirds of the total length may be used in evaluations. Thus, the will be idealized as a shell diameter and , with thickness determined from the weight, resulting in the following ***equivalent shell***:

-
-
-
-

The consists of a (Ref. 2). Since the will not impact the target simultaneously with the and since impact of the will be on a larger area, thus mitigating the impact effects, the may be considered consisting of the housing only. The is cylinder and and the housing is cylinder, Again, the assembly is idealized as a

cylinder, with total thickness of and outside diameter of . resulting in the following ***equivalent shell:***

- (the latter weight is for the and only)
-
-
-

Finally, both speeds are given as Data in Ref. 2 shows that the speed of the aircraft at is . and at Considering the height of the structures at this facility, a speed of is more appropriate. Consequently, evaluations were performed for velocity as well as the specified velocity.

4. STRUCTURAL RESPONSE ANALYSIS

effects on structures are considered in two categories: local response and global response. In local response analysis, the focus is on perforation, penetration, and, for concrete structures, spalling and scabbing. In the global analysis, the focus is on strength and ductility demand on the structural elements in the load path. Method of approach for the two types of analyses is different as described in the following subsections.

1. Local response

Local response behavior is determined by the following parameters:

In the case of the YMP structures, scabbing is unlikely to cause damage to the casks and waste packages due to the anticipated small sizes of concrete pieces at low speeds that are generated as a result of the impact. Therefore, the controlling local behavior is of the wall.

Many experiments have been performed to determine the effects of on concrete targets. The , have ranged from solid cylindrical slugs to pipe sections. The velocities have ranged from Based on test data, empirical equations have been developed to determine the target thickness required to preclude perforation. Most of these formulations are for solid , but Ref. 3 provides a conversion factor from solid to "deformable" Aircraft associated are certainly deformable and therefore, a factor is applied to the solid test data to account for the local damage.

The empirical relations developed by different investigators result in a wide range of . Ref. 3 recommends the equation developed in Ref. 4 be used for This equation is as follows:

$$t_p = \left(\frac{U}{V}\right)^{0.25}\left(\frac{MV^2}{Df'_c}\right)^{0.5} \qquad \text{Eq. 1}$$

where,
t_p =
U =
V =
M =
D =
f_c' =

Ref. 3 recommends that the minimum thickness should be than that calculated from Eq. 1 to prevent perforation. Ref. 3 also recommends that the perforation thickness for deformable missiles should be taken as from Eq. 1.

Similar tests were performed in France using solid missiles, with velocities greater and less than the "critical perforation velocity." The experiments led to the following empirical equation:

$$t_p = 0.765\left(\frac{1}{f_c'}\right)^{\frac{3}{8}}\left(\frac{W}{D}\right)^{\frac{1}{2}}(V)^{\frac{3}{4}} \qquad \text{Eq. 2}$$

where,

W = missile weight, lbs, and the other symbols are the same as before.

The factor for s also applicable here as the empirical relationship is based on tests with

Experiments using were also carried out as part of a testing program on postulated (Ref. 5). As a result of this program, the following empirical relations were developed for estimating the distance to (Ref. 5):

$$s = \frac{mV_o^2}{2F_a} \qquad \text{Eq. 3}$$

where,
s =
m =
V_o =
F_a =
F_y =
A =

The distance to can be conservatively taken as the required perforation thickness, ignoring the displacement of the target, which is presumably included in the distance deduced from the tests. The interface force can be estimated using the equivalent shell area and the yield point for steel, which can be taken as Once

the interface force is known, Eq. 3 can be used to estimate the perforation thickness. The assumption here is that deformation of the target structure is negligible.

Table 1 shows the resulting estimated concrete thicknesses to prevent perforation, using the three different equations. These three equations were selected since they result in comparable values. Calculations have been carried out for both velocities. The results show that the dominates the required concrete thickness to preclude perforation. The table also shows the required minimum thickness considering the factor recommended by the previous researchers.

2. Global Response

Accurate global response can only be determined from a nonlinear analysis using a specialty computer code that takes into account large material and geometric nonlinearities. At this stage on the YMP, such an analysis is not warranted since sufficient qualitative data can be developed to establish confidence in the behavior of the structure.

As stated earlier, the maximum interface force between the and the target structure can be calculated using the properties:

$$F_a = F_y A \qquad \text{Eq. 4}$$

This equation shows that the interface force is independent of the velocity, provided that the impact energy is sufficient to cause yielding of the

The equivalent shell parameters for both the were used to estimate the interface force due to each , as shown in Table 2. The total maximum interface force of the entire aircraft impacting a building is estimated as the force due to impact of plus (additional interface forces that may be developed by other parts of the aircraft are considered small compared to the impact forces generated by the It is conservative to assume all the interface forces occur simultaneously. It is also assumed that the target area of the building is sufficiently large so that the entire aircraft will impact the building. The maximum interface force thus calculated is about Assuming an effective impact width of about (i.e.,), the peak impact force is

This is the estimated ***demand*** on the structure, V_D, in terms of total shear.

The ***capacity*** of the structure can be estimated considering the in-plane shear capacity of the building over the impacted area. The base shear of the structure is given by:

$$V_C = W_s a \qquad \text{Eq. 5}$$

where,
V_C = the base above basemat,
W_s = weight of the structure above the basemat
a = average design acceleration

Initial design shows that the weight above grade will be about
The plan dimensions of the building will be about . Considering the longer dimension, the design base shear per unit length will be:

$$V_C = 0.5x10^6 a \text{, lbs.} \qquad \text{Eq. 5a}$$

The demand-capacity ratio is then established as:

$$\frac{D}{C} = \frac{V_D}{V_C} = \frac{1}{a} \qquad \text{Eq. 6}$$

Eq. 6 is plotted in Figure 1. When the D/C ratio is less than unity, the structure remains elastic, excluding the local crushing a spalling that may take place. Research on shear walls indicate that these walls have limited ductility. DOE-STD-1020 permits a ductility factor of for in-plane shear. It is estimated that this allowable has a factor of safety of Therefore, Figure 1 can be divided into three regions: if the base shear coefficient is the structural response remains within allowable limits. When the base shear coefficient is between , the structure is still expected not to collapse but may suffer significant deformations. Finally, if the base shear coefficient is , the structure may not survive a DBT and therefore such a design is unacceptable.

Considering the preliminary design spectra for this sight, the base shear coefficient is expected to be . Therefore, it is concluded that the DTF will withstand an impact from a DBT without suffering unacceptable damage.

5. DISCUSSION OF RESULTS

The evaluations summarized above show that the perforation thickness for the concrete walls will be controlled by the impact of the and will have an upper bound value of about For the , a thickness equal to one-half the wall thickness is considered adequate.

So far as the global response is concerned, the structure is expected to survive the DBT without unacceptable damage. This is due to the fact that the structure will be designed for large seismic forces. In fact, at this site, the structure resulting from the seismic design is expected to remain essentially elastic, excluding the spalling (near face) and scabbing (far face) of concrete.

These conclusions are consistent with Ref. 6, which has been concluded recently. This report has concluded that containment and fuel buildings at existing commercial nuclear power plants will survive a large aircraft impact without consequences. The containments generally are shells and the fuel buildings are rectangular concrete structures with approximately dimension and wall thickness. Unfortunately, details of this report are not available publicly and therefore a direct comparison is not possible.

Nevertheless, both DTF and typical nuclear power plant fuel buildings are reinforced concrete structures with similar span-to-thickness ratios for concrete walls. In a fuel building there are no intermediate walls whereas in the DTF there will be numerous walls at spacing of Consequently, it may be stated on a qualitative basis that the DTF would have lateral load capacity than a typical fuel building, given the same design basis. Therefore, the conclusions reached in Ref. 6 should be considered applicable to the DTF.

The above conclusions are arrived at using a conservative approach. This discussion will not be complete without addressing some of the conservatism associated with this qualitative study. These include:

1. Dynamic concrete strength is typically higher than the static strength by about . This strength increase is due to the high rate of loading and is ignored in the calculations.
2. The impact is assumed to be "perpendicular" to the surface. This is conservative as any deviation from perpendicular condition will tend to reduce the impact energy.
3. The global response evaluation assumes that all three components impact the building simultaneously, which is highly unlikely. Considering the fact that the impact force duration is measured in milliseconds, any difference in timing of the different components will reduce the maximum impact force.
4. In all these evaluations soil-structure interaction is ignored. Since the buildings are located at a soil site, the impact forces will be reduced with "yielding" of the soil-structure interface.
5. This evaluation has also ignored the fact that the interface force due to impact is duration, in the order of Even though the structure is rather rigid, the fundamental frequency will be in the order of thus resulting in a force duration-period ratio that will be about Dynamic amplification at these low ratios is relatively
6. The design will be based on the ACI 349 code. The in-plane shear provisions in this code are known to be conservative. Capacity of the shear walls designed in accordance with ACI 349 is calculated. This provides margin in design which is not taken into account.

6. CONCLUSIONS AND RECOMMENDATIONS

The following conclusions are reached from this study:

1. The controlling aircraft associated are the and the
2. The controlling mode is the penetration of the walls and striking a cask or a waste package.
3. Scabbing of concrete (i.e., ejection of concrete pieces from the side opposite to the impact area) will not result in damage.
4. DBT aircraft impact will not result in damage so long as the exterior wall thickness is about

5. Full impact on the is not considered a credible event. Consequently, a minimum thickness equal to one-half the thickness is considered adequate.
6. Design of the superstructure for the expected seismic forces will result in a structure with ample capacity to resist the impact effects.

Based on these conclusions, the following actions are recommended:

1. Design the facility buildings with a minimum of thickness and of thickness. These thicknesses can be if it can be shown that there will be another concrete barrier before a penetrating reaches a cask or waste package.
2. This qualitative conclusion is robust so that further, more detailed aircraft impact study is not warranted.

The above conclusions and recommendations may be further refined with a more detailed study aimed at providing a more vigorous basis for some of the assumptions involved. However, such a study is not considered high priority and may be undertaken following the LA application.

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July 14, 2003

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Table 1. Concrete Thickness to Preclude Perforation and Spalling

Type	Velocity mph	Perforation Thickness, inches					Max. Thickness inches	Design Thickness t_{max}x1.2
		Eq. 1		Eq. 2		Eq. 3		
		Calc		Calc				
		9	6	31	22	18	22	26
		12	8	38	27	33	33	40
		10	7	33	23	14	23	28
		12	8	41	29	26	29	35

Notes:
1. See text for the equations.
2. landing calculations are based on

Table 2. Peak Interface Force Calculation

Type	Equivalent Shell Diameter & Length in x in	Weight lbs	Equivalent Thickness in.	Cross-Sectional Area in^2	Interface Force lbs
	94 x 161		0.73	215	
	94 x 107		1.10	325	
	10 x 58.5		2.00	50	
	10 x 83.5		2.00	50	
Maximum possible interface force of the entire aircraft with and a					

(a) assumed to be same as the value given in the specification,
(b) assumed to be two-thirds of the value given in the specification,
(c) Equivalent h is based on diameter, total thickness of and , and volume of and
(d) Equivalent cylinder is based on higher weight of the equivalent cylinder in (c)
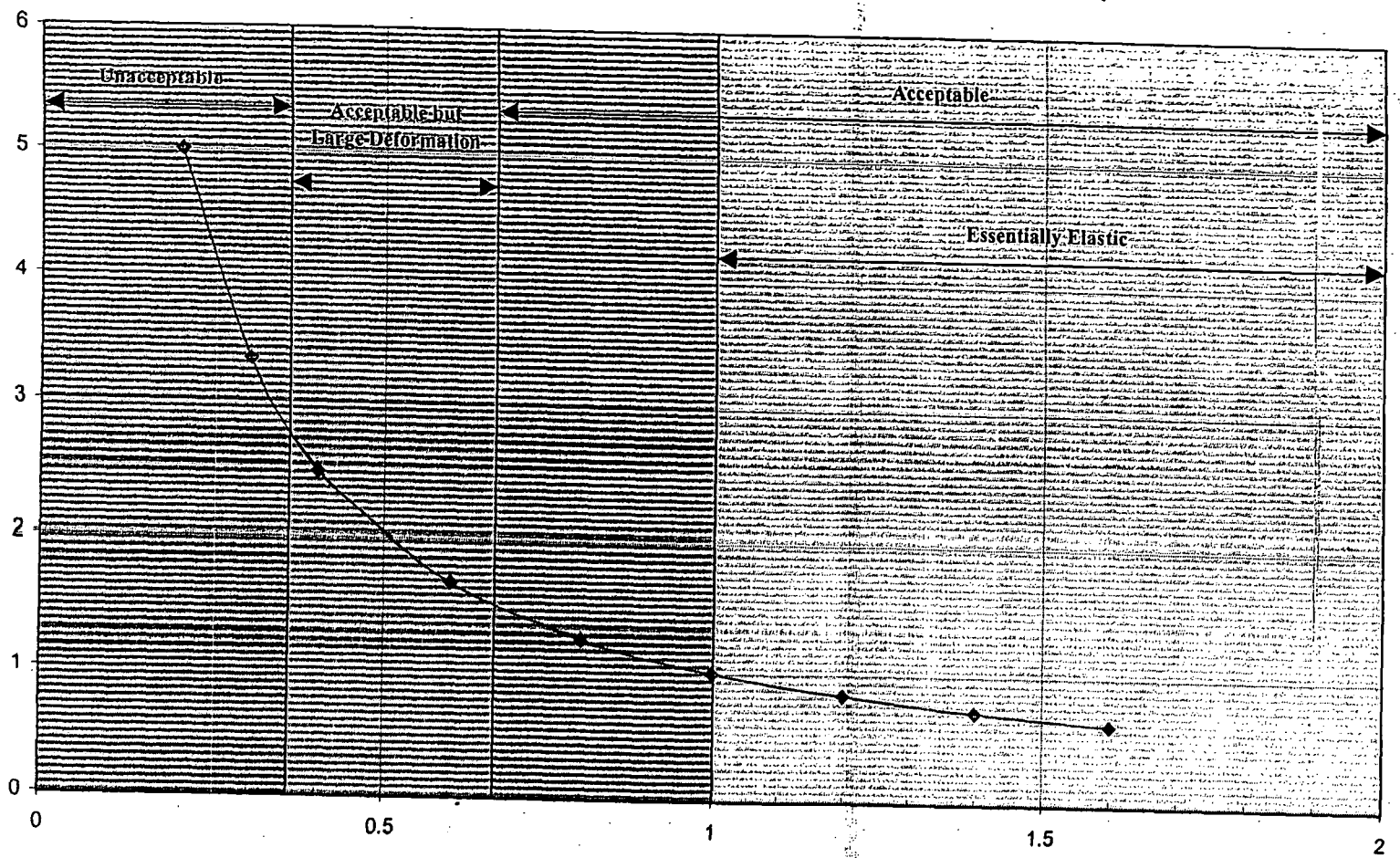
Fig. 1 Behavior under Aircraft Impact Effects