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Techno-Economic Assessment of Surface Mounding for SMR buildings

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ABSTRACT

Small powered reactors, commonly labeled as Small Modular Reactors (SMRs) have experienced a strong resurgence in interest. Currently, many nuclear regulators demand assessment of aircraft impact on nuclear structures. The consideration of such scenario in design of nuclear structures, typically puts smaller powered reactors at a disadvantage as shielding their structures from aircraft lacks economy of scale. As such, many reactor vendors propose burying their SMR concepts underground. Another solution that could potentially be less coupled to a specific site and better suit a standardized deployment approach is surface mounding of the safety significant nuclear structures. The current work aims to determine if the cost associated with the mound is lower or higher than the cost of not having it. Various scenarios are analyzed to draw conclusions about the mound's value.

INTRODUCTION

Aircraft impact remains a scenario of interest to many nuclear regulators. However, at the early years of nuclear energy development, where small powered reactors where deployed, the consideration of aircraft impact was not as extensive. Such new requirements can unfairly impact the economics of Small Modular Reactors (SMRs) and microreactors [Le Person, 2024]. Many SMRs feature large buildings, similar to large reactors such as the recent HTR-PM (High temperature gas reactor in China). As such the cost of reinforcing their building or burying them underground will be large per unit energy produced. One solution that has been proposed is to surface mound the reactor building. This study aims to determine if there are sites where the surface mound embedment technique for SMRs could lead to significant cost reductions. Various mound designs are assessed. While a surface mound might absorb some structural impacts from an airplane crash, the costs of transporting and disposing of sand or constructing an earth-dam-like structure must also be considered.

For this analysis, four types of mounds are evaluated: two non-engineered structures and two dam-like structures. The non-engineered structures involve soil material placed on top of the building without compactness considerations. The dam-like structures feature steep slopes to minimize the amount of earth material and limit the loads on the building, resembling the design and construction complexity of an earth dam. Both mound types are analyzed in configurations that either cover or do not cover the roof.

The analysis treats each mound as a sensitivity case compared to a no-mound condition for an SMR reactor building. Simplified structural analyses and estimates are conducted, dividing structural effects into local and global. The cost implications of these effects are studied separately and then combined. Various scenarios are considered, including direct costs of mound erection, the direct-to-total capital expenditure (CAPEX) ratio, and different structural design approaches.

METHODOLOGY: LOCAL VS GLOBAL EFFCTS

The NEI (ERIN, 2011) identifies two types of structural effects from an aircraft impact on a building: local and global effects. Local effects include penetration, perforation at the impact point, and scabbing on the

inner wall. Global effects refer to the overall impact on the structure, such as moments, shears, loads, and dynamic effects, which can occur far from the impact location.

The most severe local effects typically result from the aircraft engines due to their high mass and penetration power. For global effects, the entire aircraft is considered. The peak impact force of a 767, estimated at 100 MN (Brachmann, 2006), is used as the load to withstand. If the penetration depth is small relative to the aircraft's length, the RIERA curve remains valid, maintaining the maximum force of 100 MN also valid.

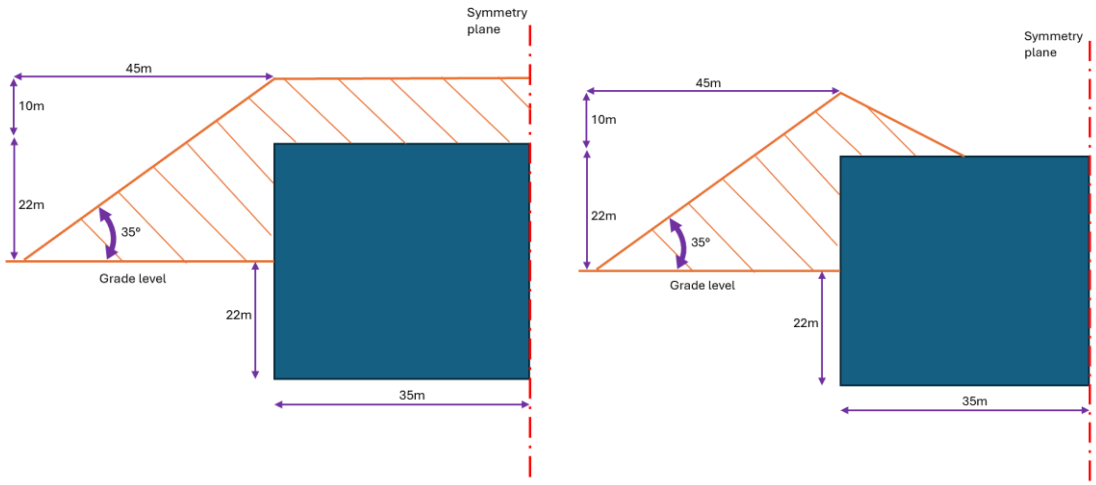
The strategy for analyzing the cost impact of the mound involves two main steps. First, the study assesses whether surface mounding as an underground siting strategy is cost-effective for mitigating local effects, specifically avoiding perforation, as per NEI (ERIN, 2011). Once this is evaluated, the second step includes the additional costs associated with global effects, not only from the aircraft but also from the mound itself, such as added weight and earth pressures. The extra costs for addressing global effects from an airplane crash stem from the necessary reinforcement to handle loads, moments, shears, etc., far from the impact point within the building.

Building Dimensions and Mound Layout

The study focuses on the EDF (Electricité de France) NuWard building, configured back in 2019 (currently NuWard is undergoing a redesign), with dimensions of 70m by 70m and a height of 44m. The building is partially underground, extending to mid-height below ground level. Four types of mounds are analyzed: two non-engineered structures and two dam-like structures.

- **Fill Mound**: Non-engineered, consisting of soil material poured atop the building without compactness considerations, with a slope angle of 35˚.
- **Dam Mound**: Engineered with steep slopes (around 60˚) to minimize soil material and limit loads on the building, similar in design and construction complexity to an earth dam.

Both mound types are evaluated in configurations that either cover or do not cover the roof. The dam mound's stability and acceptable loads are ensured through selective soil material processes, compaction, and drainage design typical of earth dams.



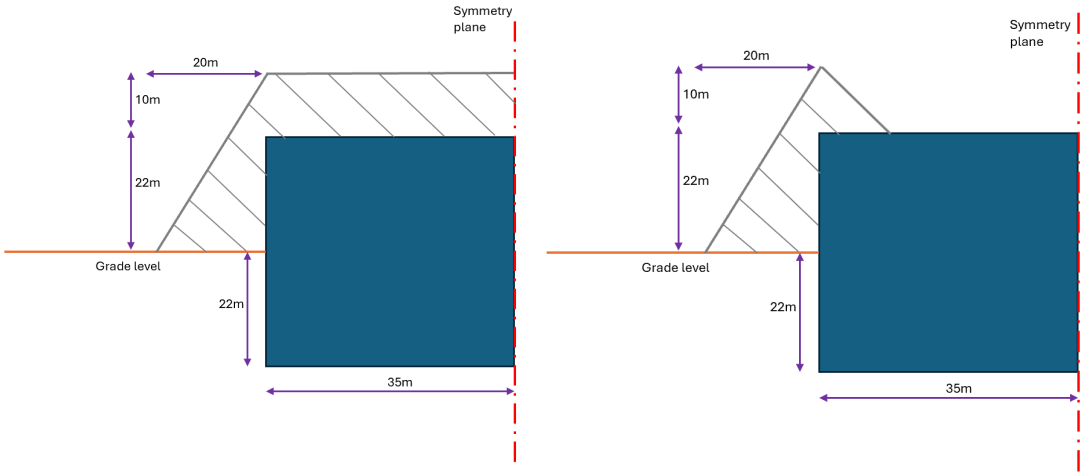


Figure 1. Top: fill mounds. Bottom: dam mounds. Left: totally covered (full mound). Right: side covered (side mound). Reactor building in blue. Fill mound in orange. Dam mound in gray.

LOCAL EFFECTS

Penetration depth

The required thickness to prevent perforation differs between soil and concrete. According to the NEI (ERIN, 2011) methodology, an aircraft engine with a diameter of 2.5 meters and a speed of 150 m/s requires approximately 90 cm of concrete to avoid perforation. The penetration depth in an infinite concrete block is about 36 cm, giving a penetration-to-perforation ratio of 0.4. Therefore, the necessary concrete thickness to prevent perforation is roughly 2.5 times the penetration depth in an infinite medium.

Three different methods are used to assess penetration depth:

- **NEI (ERIN, 2011) Procedure**: Specifically for aircraft impact.
- **Dynamic Stopping Equation:** Solves the stopping balance equation in terms of position, assuming the pressure at the projectile's front face is proportional to a fictitious shear/compressive stress at failure. The failure strength is taken as 35 MPa (compressive strength of concrete) and the fictitious stress estimated at 20 MPa. Different shaft pressure assumptions are made: 1 Pa and 1 MPa. Equation 1 shows the stopping balance equation (Jen, 1992).
- **Young Equation:** An empirical relation for assessing penetration depth of projectiles in various materials (Bernard, 1979; Fragazy & Taylor, 1989).

$$mv\frac{dv}{dx} = A_{tip}\sigma_{tip} + A_{shaft}(x)\sigma_{shaft} \quad (1)$$

Table 1 presents the penetration depth analysis for an aircraft engine (2.5 m diameter, 2 metric tons) and a military projectile (180 kg, 16 cm frontal diameter). This comparison helps evaluate the effectiveness of underground siting for protection against missiles versus aircraft impacts. Penetration depths are assessed for concrete (σc = 35 MPa) and various soil types: hard (Hsoil), medium (Msoil), and loose (Lsoil), corresponding to soil constants (S) of 5, 15, and 50 in the Young equation. Upper bound (UB) and lower bound (LB) values are based on a nose factor (N) of 1 or 1.5 for each soil type. For concrete, UB and LB also consider an S factor of 0.2 and 1.

Table 1: Penetration depth by engine/missile in concrete (with 2 hypotheses, C-h1 and C-h2) and soil

Projectile	Aircraft Boeing 767 engine					Missile			
Medium	C-h1	C-h2	Lsoil	Msoil	Hsoil	C-h1	C-h2	Lsoil	Hsoil
V(m/s)	150	150	150	150	150	150	150	150	150
Tip stress (MPa)	20	20	-	-	-	20	20	-	-
Shaft Stress (MPa)	1	10^(-6)	-	-	-	1	10^(-6)	-	-
Diameter (m)	2.5	2.5	2.5	2.5	2.5	0.16	0.16	0.16	0.16
Mass(kg)	2,000	2,000	2,000	2,000	2,000	180	180	180	180
Tan delta	0.5	0.5	-	-	-	0.5	0.5	-	-
X(m) NEI	0.36	0.36	-	-	-	-	-	-	-
X(m) Jen	0.23	0.23	-	-	-	2.72	5.04	-	-
X(m) Young LB	0.06	0.06	14.9	4.5	1.5	0.3	0.3	75.2	7.5
X(m) Young UB	0.45	0.45	22.3	6.7	2.2	0.45	0.45	112.7	11.3

Military missiles, due to their higher weight-to-area ratio and typically greater impact velocities, penetrate deeper than aircraft engines under similar conditions. From Table 1, three conclusions can be drawn:

1. The three methods provide somewhat consistent results, indicating their reliability.
2. The weight-to-area factor results in greater penetration depths for military projectiles compared to aircraft engines. Therefore, surface mounding is more suitable for protecting military structures than nuclear power plants (NPPs).
3. The maximum penetration depths for an aircraft engine in loose soil (Lsoil), medium soil (Msoil), and hard soil (Hsoil) are approximately 22.3 m, 6.7 m, and 2.2 m, respectively. With a nose factor of 0.5 and the previously discussed perforation/penetration ratio of 2.5 (justified before), the adjusted depths to avoid perforation are 27.5 m, 8.75 m, and 2.75 m. Consequently, the soil volume forming the mound, as shown in Figure 1, should not be reduced.

Preventing Local Effects with Mound

Local effects are assumed to be resisted either by the mound, if present, or by the external wall thickness. This section does not include the extra reinforcement needed to resist global effects from an airplane crash, dead weight pressures, or seismic loads. Therefore, the cost-effectiveness of the mound for addressing local effects is simplified to the additional wall thickness required without a mound, minus the cost of the mound. Equation 2 illustrates the cost difference, indicating the mound's worthiness: positive values mean the mound is cost-effective, while negative values mean it is not.

$$Cost\ difference = Cost\ (\Delta wall)[\$] - \text{Cost Mound}\ [\$] \tag{2}$$

The calculated cost differences impact the final capital cost of the project. The cost of reinforced concrete is derived from industrial data on steel rebar and concrete for NPPs (Champlin, 2018). These integrated unit costs include the purchase and labor costs. Other costs, such as transportation or storage of concrete and steel, are assumed to have a minimal impact. The direct cost of steel rebar is \$36,000/m³, and the direct cost of concrete is \$650/m³. Applying a 3X factor to convert to capital cost results in \$108,000/m³ for steel and \$1,950/m³ for concrete.

Sensitivity on Estimated Cost: three variables

In this study, we analyze the sensitivity of three variables on cost:

1. **Cost of Earth Material:** The cost per cubic meter of fill or dam mound material.
2. **Wall Thickness Increase:** The method by which the wall thickness needs to be increased.
3. **Direct to Capital Cost Conversion Factor:** The factor used to convert direct costs to capital costs in dam construction.

The cost per cubic meter for dam and fill mounds includes all procedures required to construct the mound around the building, such as earth retrieval, hauling, mound design, and constructing auxiliary structures. Two cost ranges are defined for each mound type, expressed in terms of total capital cost (ΔCAPEX/Δm³ earth):

- **Dam Mound**: $30 to $200/m³, based on the total CAPEX of constructed earth dams (Petheram & McMahon, 2019).
- **Fill Mound**: $10 to $90/m³, derived from excavation and hauling costs (Plotner, 2017), with a 3X factor applied to convert direct costs to CAPEX.

The second variable analyzed is the **method of increasing wall thickness**. Since local effects from an aircraft impact are expressed in terms of concrete penetration depth, no additional steel reinforcement is needed for local effects. However, seismic requirements or earth pressures may necessitate additional rebar when increasing the external wall thickness to mitigate local effects.
Two scenarios are considered:

1. **Concrete Only**: Increasing wall and/or roof thickness with concrete alone.
2. **Concrete with Reinforcing Steel**: Adding a 2% density of reinforcing steel along with the concrete.

The estimated wall thickness without an airplane crash is 20 cm, and the roof thickness is 30 cm, which aligns with typical design code minimums. Figure 2 illustrates the thickness increase due to the absence of a mound for local effects, with both steel reinforcement scenarios. Note that wall thickness may still need to increase for global effects reinforcement, which is addressed separately in the study.

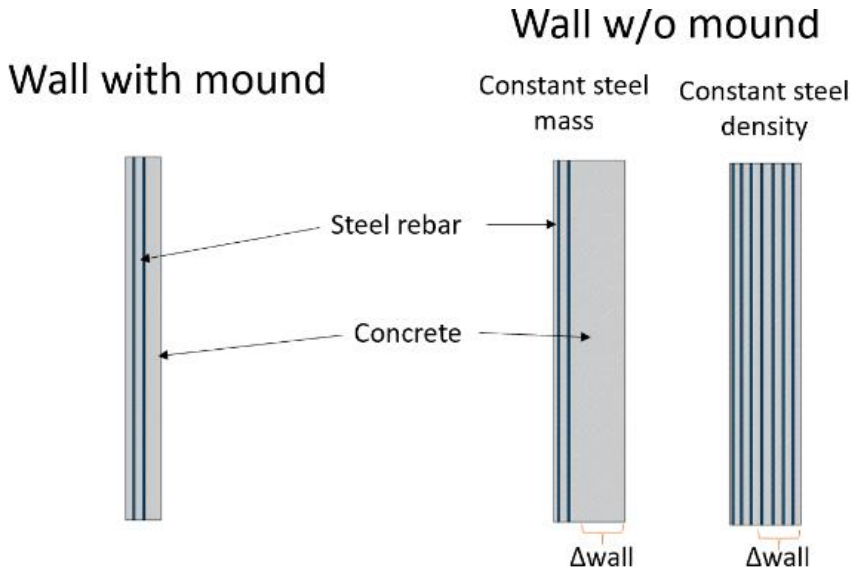


Figure 2. Increase in concrete wall thickness without mound (two cases)

The third variable is the **direct cost to capital cost conversion factor**. For NPPs, this factor is fixed at 3X, derived from a 1.37X financing factor (8 years at 4% per year), a 2X direct to indirect cost factor, and a 1.1X overhead factor: 1.37 x 2 x 1.1 ≈ 3X.

For dams, sensitivity is assessed with two conversion factors: 3X (similar to NPPs) and 1.5X. The 1.5X factor results in higher cost estimates for dam mounds. Given the database on earth dam projects (Petheram & McMahon, 2019), it is reasonable to assume similar direct to capital cost factors, as most projects are completed in 5 to 10 years, with some taking over 20 years and often exceeding budgets by 50% to 250%. Some projects are comparable in volume to the top case in Figure 1. Only the 3X factor is applied to the fill mound case, as its unit direct cost is certain. Scabbing is not considered in this study, assuming a thin liner attached to the wall can prevent it.

Local Effect Cost Savings in full mound

Table 2 shows the cost differences associated with local effects for each of the cases described above.

Table 2: Local effects Capital cost difference (full mound)

Total CAPEX difference in $M	Dam mound				Fill mound: 35°	
Direct-to-CAPEX	Nuclear (3X)		Non-nuclear (1.5X)		Does not apply	
Constant steel	Mass	Density(2%)	Mass	Density(2%)	Mass	Density(2%)
Lower bound soil cost	9.5	25.3	4.8	20.7	10.8	26.6
Upper bound soil cost	-16.9	-1	-47.9	-32	-16.2	-0.4

The potential cost savings from using a cheaper protector, such as anti-penetration panels, instead of increasing roof thickness were estimated. Assuming these panels are 50% cheaper than the required 60 cm roof thickness increase (from 30 cm to 90 cm), the cost reduction would be around $4M to $8M, depending on whether constant steel mass or density assumptions are used. However, this option is excluded from the analysis. If each building houses two reactor units totaling 600 MWe, and the capital cost is $3M/MWe (optimistic scenario), the total capital cost is $1,800M. The savings from a cheaper roof protector would be less than 0.5% of the total capital cost, even in the best-case scenario with constant steel density. Table 2 indicates that for the fill mound case, the range of cost differences is approximately $[0, -15]M for the upper bound soil cost and $[10, 25]M for the lower bound earth cost. For the dam mound case, the range is $[0, -50]M for the upper bound and $[5, 25]M for the lower bound. The -$50M in the upper bound case is significantly influenced by the 1.5X direct to capital cost multiplication factor for dams. This assumption may be excessive, suggesting a more reasonable range of $[0, -15]M instead of $[0, -50]M. Note that the 1.5X or 3X direct to capital cost multiplication factor are what we assume in this study to dams, not to nuclear reactors. The nuclear and non-nuclear titles indicate whether the conversion is the typical for nuclear reactor projects. Assuming a lower multiplier (1.5X) results in a higher capital cost, since the capital cost for dams is the input and a smaller multiplier results in higher direct cost of the mound.

PREVENTING GLOBAL EFFECTS WITH FULL MOUND

To prevent global effects, structural reinforcement is employed in this study to resist various loads on the building, not just from the aircraft impact. This includes additional loads from the mound, such as earth pressures on the building's sides, dead weight on the top, and added mass during an earthquake. These reinforcements are crucial for evaluating the cost-effectiveness of the mound. The interaction between the

mound and the building structure varies significantly at the roof and walls. An engineered mound (dam mound) can be designed to minimize side loads, while the fill mound's earth loads depend solely on soil nature and wall flexibility. Additionally, the mound's design can direct some impact loads directly to the ground, reducing the effect on the building structure.

The dual definition of mounds—dam mound (engineered) and fill mound (non-engineered)—is particularly useful for analyzing load transmission. Two enveloping cases are defined to represent the spectrum of impact loads:

1. **Dam Mound**: No airplane impact loads on the side are transmitted to the building. Earth pressures are not transmitted to the walls.
2. **Fill Mound**: All airplane impact loads on the side are transmitted to the building. Earth pressures are fully transmitted to the walls.

This distinction helps in understanding how different mound designs affect load transmission to the building structure, as illustrated in Figure 3 (left).

Due to the lack of tensile strength in soil materials, the weight of the mound above the building will be fully transmitted to the building structure, regardless of whether it is a dam or fill mound. Additionally, the entire vertical component of an impact on the roof will be transmitted to the building structure. This is because the soil layer above the roof (70x70x10m) lacks bending resistance (shown in Figure 3, right sections with no bending resistance), causing loads to travel through the roof structure. If the mound layer above the roof were thicker than the smaller dimension of the roof area, a significant portion of the earth's weight would be transmitted through the sides to the ground, reducing the load on the building.

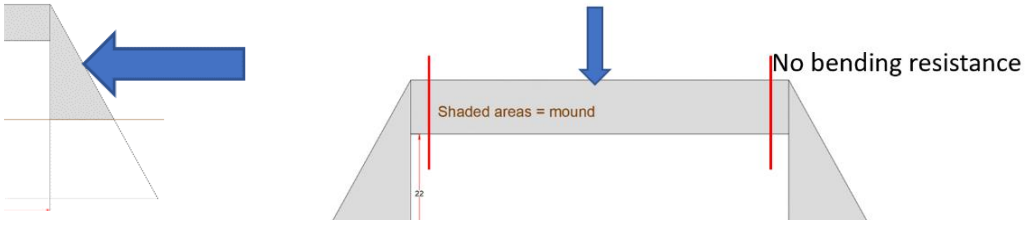


Figure 3. Left: impact on the side of the mound. Right: impact on the roof

Similarly, the entire mass of earth above the building vibrates with the roof in the vertical direction, acting as added mass. During an earthquake, this magnifies the roof's vibration modes vertically, and the vertical accelerations of the mound are fully transmitted to the building structure.

The CAPEX differences associated with global effects need to be added to the previously calculated CAPEX differences for local effects. The need for additional reinforcement to address global effects depends on the building's inherent stiffness and robustness, which are design-dependent. Buildings with more floors and rooms are generally stiffer, and higher earthquake requirements typically necessitate greater stiffness and robustness. If the building's design already provides sufficient structural capacity to handle global effects, the CAPEX impact is null. Conversely, a weaker building may require additional reinforcement to absorb loads, moments, shears, etc., from global effects. These scenarios represent the upper and lower bounds of CAPEX addition: the lower bound entails no additional CAPEX, while the upper bound includes the maximum necessary reinforcement.

Three upper bound CAPEX figures are determined, each representing the necessary CAPEX increment for reinforcing the structure against:

1. Earth pressures from the side of the mound.
2. Additional structural needs to support the earth on the roof.

3. Additional structural needs to cope with a side crash.

The global effects associated with a vertical impact on the roof (or its vertical component) are not different with or without the mound in this model. Among the three CAPEX figures, the one that significantly increases costs is the structural reinforcement needed to support a 10 m layer of earth above the building's roof, estimated at $70M. This figure, though seemingly high, becomes reasonable when considering the load it must resist. The total mass of a 10 m earth layer is approximately 100,000 metric tons, exerting a permanent downward force of 1 GN on the structure, which is 10 times the peak force of an airplane crash considered in this study. The dead weight of the mound is a load that needs to be resisted permanently and the load coming for the impact is a boundary condition, thus the factor is larger. The theoretical section of concrete needed to resist this load at 10 MPa of compression is 100 m². Multiply this area by the height of the building, 44 m, and we get 4400 m³ of concrete, costing $8.5M. Adding 2% steel reinforcement increases this to $17M. If steel members are used instead, the cost rises to $47.5M. A realistic solution, combining various materials and accounting for inefficiencies, might cost around $32.25M.

Considering seismic loads, with an assumed 0.3g acceleration and seismic amplification, the cost doubles to $64.5M. Additional inefficiencies due to NPP's SSC constraints further increase the cost, rounding the final figure to $70M. We estimated $70M for reinforcing the structure to support approximately 100,000 tons of earth, which is about one-third the mass of the Empire State Building(Realty, 2019). The Empire State Building's current estimated cost is around $600M (according to Wikipedia), so one-third of that is $200M. Although the reactor building is seismic class one, the Empire State Building likely uses more expensive materials and design. Therefore, $70M for reinforcing the structure to support this mass, including additional structural members and design adaptations, seems reasonable.

The additional CAPEX for mitigating the global effects of a side aircraft crash and earth pressures at the side are both estimated at $35M. The moments caused by earth pressures at grade level, assuming $k=\sigma h/\sigma v=1$, exceed those from a side crash at the building's top. However, the load distribution from an aircraft crash is more irregular, balancing the higher moments and shears at the base due to earth pressures. The $35M estimate assumes moments from earth pressures are managed by multiple rows of tie-back anchors. While internal stiffening is preferred, this calculation provides an upper cost estimate for reinforcement, serving as our model's reference quantity.

COST WORTHINESS OF FULL MOUND

According to our model, **local effects** result in the following ranges of CAPEX differences:

- Fill mound: UB $ [0,-15]M, LB $ [10,25] M
- Dam mound: UB $ [0,-50]M, LB $ [5, 25] M

The global effect additions are capped at $35M for mitigating the effects of a side aircraft crash and side earth pressures, and $70M for the mass of earth on the roof. We consider two scenarios:

1. A structurally robust building that requires no internal reinforcement.
2. A weaker building needing all the internal reinforcements previously described.

For the first scenario, the **total CAPEX differences** arise solely from local effects. For the second scenario, the total CAPEX differences combine local effects with $35M for reinforcement against side crashes and earth pressures, positive for the dam mound, since it represents savings in reinforcement against airplane crash, and $70M for the earth mass on the roof:

- Fill mound (-35-70) = -105: UB $[-105,-120]M, LB $[-95,-80] M
- Dam mound (+35-70) = -35: UB $[-35,-85]M, LB $ [-30, -10]M

If the building is inherently stiff and robust, requiring minimal additional reinforcement for global effects, and the associated earth costs are low, there can be a positive cost difference from the mound. The highest positive CAPEX difference is similar for both fill and dam mounds, ranging from $10M to $25M and $5M to $25M, respectively. However, the fill mound has a larger negative CAPEX difference compared to the dam mound, ranging from $[-105M to -120M] versus $[-35M to -85M]. Therefore, opting for a carefully engineered structure (dam mound) is generally less risky than a simple excavation and pour (fill mound). The worst negative outcome significantly outweighs the best positive outcome, with potential savings of approximately $15M versus potential losses of $50M to $100M. Thus, fully covered mounds, as shown in Figure 1, left, do not typically reduce costs. These results are specific to the final layout, as they depend heavily on the amount of additional global reinforcement needed. With the need for global reinforcement, the potential savings of approximately $15M diminish, making the mound strategy even less worthwhile.

The analysis indicates that the 10-meter roof cover is more of a hindrance than a help, due to the up to $70M in reinforcement costs and its inability to absorb global structural effects from an airplane crash. Additionally, the building's vertical direction is more likely to require full global reinforcement compared to horizontal effects like side earth pressures or side crashes. There are likely more floors and rooms on the building's sides that stiffen the structure than at the top. In consequence, while the mound may provide benefits to the building's sides, the roof cover is less beneficial. Removing the earth layer from the roof results in side mounds, as shown in Figure 1, right. **The next step is to use the same methodology applied to fully covered surface mounds to evaluate the worthiness of side mounds**.

COST WORTHINESS OF SIDE MOUND

As in this case there is no mound at the roof, the $70M penalty does not apply. The process is the same:

Table 3: Local effects Capital cost difference in side mound

Total CAPEX difference in $M	Side dam mound				Side fill mound: 35°	
Direct-to-CAPEX	Nuclear (3X)		Non-nuclear (1.5X)		Does not apply	
Constant steel	Mass	Density(2%)	Mass	Density(2%)	Mass	Density(2%)
Lower bound soil cost	5.2	14.6	2.0	11.4	5.5	14.9
Upper bound soil cost	-12.8	-3.4	-34	-24.6	-17.5	-8.1

When accounting for the -$35M needed to resist the global effects of a crash and the side earth pressures, **the fill mound is not cost-effective** in scenarios requiring substantial global reinforcement. However, due to the likely presence of dense flooring and rooms on the building's sides, minimal reinforcement might be needed. In such cases, the mound could be marginally cost-effective, by a few million dollars.

When accounting for the +$35M saved from needed reinforcement to resist global effects of a crash, **the dam mound becomes cost-effective in all scenarios**. This is due to its ability to absorb global effects and prevent earth pressures, achievable only if the mound is not supported by the building. The 1.5X assumption in Table 3 is severe, thus regarding local effects, the lower bound is likely $[5,15]M and the upper bound $[-5,-15]M. Applying the +$35M factor for preventing global effects results in $[40,50]M and $[30,20]M. Even in the worst-case scenario (3X assumption and data from Table 3 + $35M) of a $20M benefit, there is still room for reinforcement against side global effects, if needed, maintaining cost-effectiveness. Given that the building's sides have more flooring and rooms than the top, it is advisable to use the dam side mound. The model indicates that even if the dam mound is not supported by the reactor building wall, the dam side mound will generally be cost-effective, if the assumptions in this study hold valid.

It's also important to note that this analysis does not account for the increased CAPEX due to extended construction time for the surface mound. Earth dams with similar soil volumes can take 3-5 years to complete. Assuming a mound takes an additional 0.5 years to complete, with a NOAK CAPEX of $1,800M and an interest rate of 6% per year over a 6-year construction period, the extra 0.5 years would increase CAPEX by $54M. This financial cost outweighs the potential savings from side or top mounds. Therefore, unless the mound can be constructed in less than 2 months or concurrently with other activities without significant delays, it will not be cost-effective.

CONCLUSIONS

The study recommends removing the mound from the building's roof and considering an engineered earth structure. A fill mound solution may be economical if site soil movement costs are low. Results depend heavily on the building's size and internal structures. Sensitivity analysis with reduced-to-half reactor building height and span, still embedded to mid-level, shows a positive trend in economic competitiveness for all the mound cases when reducing reactor building size. The side dam mound case is also positive. Other mound cases may be slightly positive or less negative relative to the assumed total project cost compared to the larger reactor building. Floors and walls can enhance building robustness and protect SSC, potentially making surface mounding unnecessary.

This study is primarily theoretical, aiming to draw general conclusions. It serves more as a summary of the caveats of surface mounding cost-effectiveness, useful for basic design decisions and as a reference for specific cases, rather than for detailed cost analysis. Each design and its conditions are unique, and the optimal solution can vary significantly depending on the site. For example, if a building has specific internal spacing and is located on a gravel site, adding a 2-meter gravel layer at the top might address local effects without adding excessive weight. This could absorb local effects at the top without needing additional reinforcement. Side mounds could then be optimized by using nearby clay, compacted and strategically layered with gravel for drainage.

Unaccounted factors, such as savings in plant security or the dynamic response of SSCs to an airplane crash, could improve the case for the mound, potentially altering the study's conclusion. However, the financing cost penalty from the mound is likely higher than estimated due to extended construction timelines for SMRs.

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