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STRUCTURAL QUALIFICATION OF NUCLEAR PLANT FACILITIES AND EQUIPMENT TO HIGHER CAPACITY DRY STORAGE SYSTEMS

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ABSTRACT

While waiting for a federal nuclear waste repository, US plants are resorted to store sufficiently cooled spent nuclear fuel on the interim dry storage facilities, also known as Independent Spent Fuel Storage Installations (ISFSI) commonly co-located adjacent to the plant. The available space on existing ISFSI storage pads is limited, hence it is increasingly necessary to implement dry storage systems with higher storage capacity.

In response, the vendors have offered higher capacity storage containers without significantly increasing the footprint area on the pad. The upgrade usually boosts the capacity of available storage up to thirty percent and accommodates the High Burnup spent fuel. However, it may also increase the weight imposed on Plant structures. Typical affected structures are Spent Fuel Pool, Fuel Handling Building Floor, Hauling Path, and ISFSI pad.

Transition details to a higher capacity storage system for a plant located in Northeastern US is presented. This study provides a review of loads imposed on the plant facilities by the higher capacity dry spent fuel storage containers. The equipment descriptions used throughout the paper are sometimes specific to this plant and the dry cask vendor, nonetheless all plants and dry cask vendors in the US use similar methods and procedures. The margins of safety for some structural qualifications of Plant structures are provided to illustrate remaining capacity. Additionally, the paper provides qualification details for unanchored equipment and explains a load rating analysis for the heavy lifting equipment utilized during typical ISFSI projects across the US.

The review also serves as a general guideline for navigating through the engineering, licensing, and regulatory requirements in implementing dry storage systems needed for the younger generations to close the gap in knowledge of nuclear industry engineering practices.

INTRODUCTION

The transfer of sufficiently cooled spent nuclear fuel starts from Spent Fuel Pool (SFP) located in Fuel Handling Building (FHB) of the Plant. The SFP is approximately 43 feet deep, filled with the clean water under recommended temperature of less than 130°F. This plant is of BWR type, whereas PWR plants use borated water, however temperature limits are similar. The fuel cladding temperature at the time of transfer is about 650°F. The fuel is carefully loaded into about 1 inch thick, 190-inch-tall stainless-steel cylindrical canister having diameter of about 76 inches, with an internal cell basket made or lined up with neutron-absorbing material designed to maintain fuel subcriticality level within the limits, listed in 10 CFR 72 and

NUREG-1536 (1997). Major dry casks vendors, such as HOLTEC®, ORANO®, and NAC® refer to these canisters as Multi-Purpose Canister (MPC), Dry-Shielded Canister (DSC), or Transportable Storage Canister (TSC) respectively.

The fuel loading operation is performed from the Fuel Handling Platform (FHP) which travels along SFP and is equipped with telescopic mast and the grapple that handles the fuel bundles. The Transfer Container/Cask used to remove the Canister from the SFP is a heavy-duty cylinder that provides shielding. These Transfer containers are usually designed to weigh less than 250 kips (125 ton) due to FHB crane capacity limitation. US plants generally feature either 200 kips or 250 kips capacity FHB cranes. The Transfer container is cleaned from SFP water on Decontamination Pad (DECON Pad). Once the Canister is sealed, it is transferred into the permanent Storage Container/Cask within or outside of the FHB, using appropriate equipment available at the Plant, such as rail carts, trailers, movers, and lifters typically purchased or leased. The Plant purchased a device, specifically designed to handle vertical containers, referred to as Vertical Cask Transporter (VCT), see Figure 1. The storage container is then moved by the VCT to ISFSI pad via Hauling Path, which consist of Turning Slab and Bridging Slab. On the ISFSI pad the permanent Storage Container is lowered and positioned in place. The distance between the vertical containers, referred to as pitch, is 17 feet. The complete cycle, referred to as campaign, is shown on Figure 1.

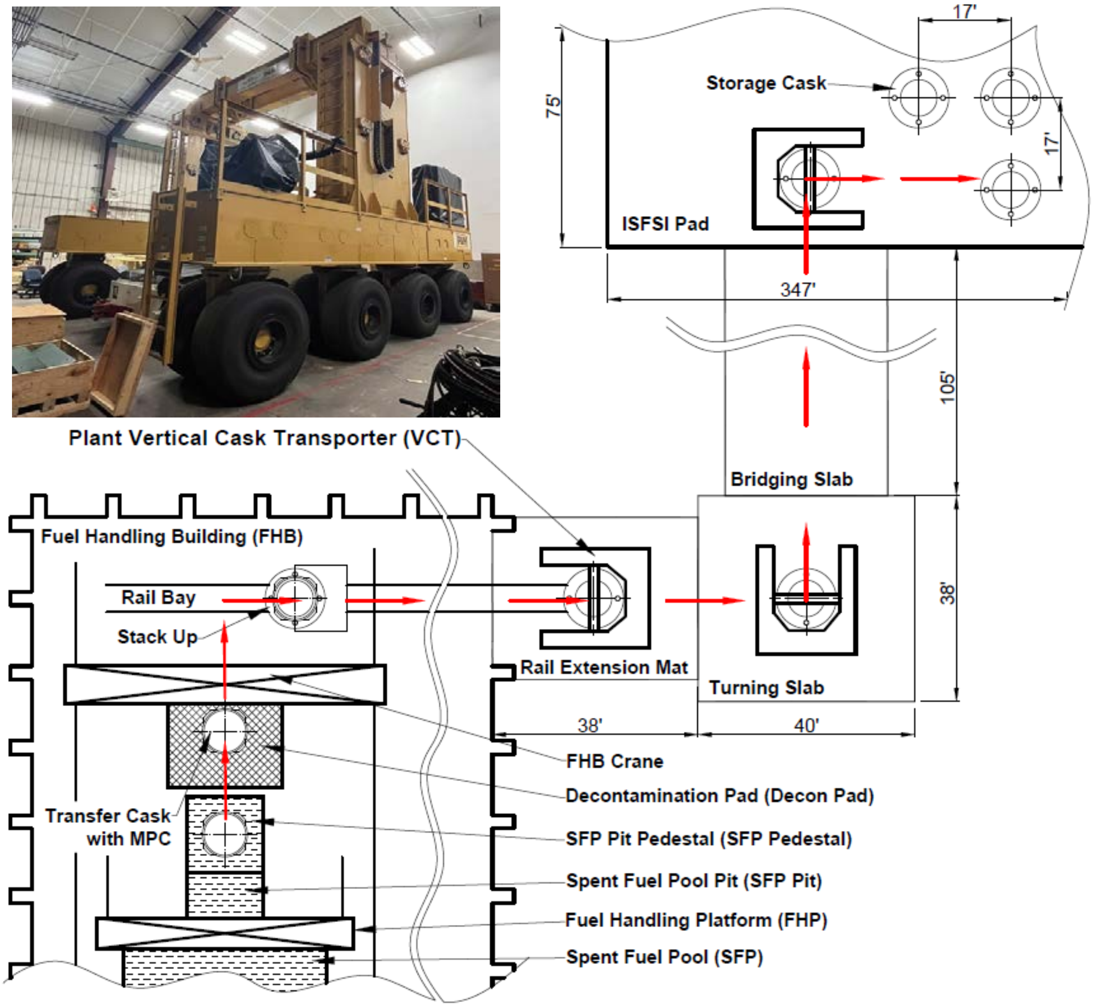

Figure 1. FHB facilities, Haul Route, ISFSI Pad, and Plant VCT

Dry Spent Fuel Installation and associated operations are licensed to 10 CFR Part 72, whereas FHB is the 10 CFR Part 50 facility. The crossover review is initiated through 10 CFR 50.59 screen/evaluation process to determine, whether any of the dry fuel operations have any adverse impact on the Part 50 facilities. The 10 CFR 72.212 report is issued to conclude that the plant meets Part 72 and Certificate of Compliance (COC) requirements either by being bounded by the Cask FSAR or site-specific analyses. The design basis requirements are usually defined in Plant's Updated Final Safety Analysis Report (UFSAR) or Safety Evaluation Reports (SER). Typically, the cask vendor provides the structural qualification of structures and components related to an upgrade, as part of 10 CFR Part 72 process, however the Plant is also required to perform owner's acceptance review (OAR) of project deliverables.

For the conversion to other storage systems, including the upgrade to higher capacity storage, the 10 CFR 72.48 evaluation is used to determine the impacts on existing Part 72 facilities. The change is usually, but not always, require a License Amendment Request to be issued to the Nuclear Regulatory Commission (NRC). Any changes are required to be in compliance with Part 50 license.

The FHB structure and Rail Extension Mat are classified as Safety-Related-Class-I structure (by Part 50 terminology), and as such, the requirements for structures located within the building should satisfy the applicable loading requirements. This ISFSI pad is defined as Important-to-Safety-Category-C using Part 72 terminology. However, there are several other pads, specifically older pads, that were designed as non-safety related facilities. Haul Path is classified as Not-Important-to-Safety (NITS), see NUREG-6407 (1997) for details.

DESIGN BASIS ANALYSIS

The scope of review affected by the installation is defined by the requirements listed in Plant UFSAR and specific NRC requirements, defined in NUREG-1536 (1997) and NUREG-1567 (2000), which are along with ISG-1 through ISG-26, are now consolidated in NUREG-2215 (2020). The typical analyses are shown on Table 1, along with the applicability to various locations, see Figure 1.

Table 1: Design Basis Analyses for SFDS installation

Analysis Type	**SFP**	**FHB**	**Haul Path**	**ISFSI Pad**
Transfer/Storage Cask Stability/Seismic Load	Yes	Yes		Yes
Floor/Pad Structural Capacity	Yes	Yes	Yes	Yes
Fuel Drop[1]	Yes			
Transfer/Storage Cask Drop and Tip-over	Yes	Yes	Yes	Yes
Fire/Explosion Hazards		Yes	Yes	Yes
Aircraft Strike[2]				Yes
Flood and Wind Analyses				Yes
Thermal Analysis[3]		Yes		Yes
Tornado Induced Missile Strike[4]	Yes	Yes	Yes	Yes
Electrical Mast/Tree Fall				Yes
Drainage Analysis				Yes
Buried Utilities Evaluation			Yes	Yes
Subgrade Bearing Capacity		Yes	Yes	Yes

Notes:

1. A fuel drop analysis may not be necessary, if the lifting equipment is qualified as single-failure-proof, see section below on Heavy Lifting Equipment. There are two postulated

types of fuel drop: 1) the fuel bundle drop on the SFP storage racks, and 2) the fuel bundle drop on the MPC basket cell.

2. An aircraft strike is not typically a design basis event; however, it can be feasible given the probability of aircraft accidents resulting in radiological release greater than 10 CFR Part 100 exposure guidelines. It may be required due to proximity to airports or flight airways.
3. Thermal analyses include: 1) the fire within FHB building, 2) the fire of the mover, a crane, or VCT, 3) an elevation in temperature due to blockage of Storage Containers ducts by debris or flood.
4. Tornado and high wind induced missile strikes typically affect the outdoor facilities, per Regulatory Guide 1.13, and Standard Review Plan 3.5.1.4 of NUREG-0800. However, in some instances, such as temporarily opened cargo gates, small missiles can penetrate and affect the internal safety-related systems.

The scope of review is communicated in Procurement Specification (PS) which is issued to the Contractor. PS defines important project positions, such as deliverables by each side and project timeline, identifies stakeholders, describes working documents and procedures, clarifies site specific data and documentation, as well as provides ALARA dose rates during all phases of fuel transfer operations, as required by 10 CFR Part 20.

Since most Plants by now have Spent Fuel Dry Storage facilities (SFDS) in place, Engineering Change Package (ECP), or just Engineering Change (EC), which provides the basis for the switch to the new system is prepared and reviewed by all engineering personnel involved in SFDS project. In addition to principal analyses listed in Table 1, there are several analyses related to an engineering review of various ancillary equipment used by the Cask Vendor/Contractor, which requires an approval review by the Plant. Once the ECP/EC is prepared and approved, the installation can begin. Storage System FSAR (initial, or its revision) and its Certificate of Compliance (COC) should have also been approved by NRC by the time the campaign starts.

UNANCHORED EQUIPMENT IN SAFETY-RELATED AREAS

The stability of both, Transfer Cask and Storage Cask, during the postulated seismic event, must be demonstrated at each stage of the fuel transfer operation. Such analyses provide the confidence that during an event the cask will not tip-over or collide with other safety-related equipment within Part 50 facility. The cask is generally allowed to slide or rock within the limits defined in ASCE 43 (2005) or ASCE 4 (2016), for rocking and sliding of unanchored rigid bodies. The industry standard frequency-domain analyses, such as response spectrum, cannot be used herein, since the estimation of fundamental frequency, and the structural damping is unclear for unconstrained bodies. However, dynamic analyses can be performed using rigid body approach by representing the casks, floor and other equipment as rigid bodies and defining the contacts between them as elements having the contact stiffness and contact damping activated upon impact between the bodies. Simulation packages, such as ANSYS® and LS-DYNA®, can perform time history analyses on such models and hence are widely used for stability calculations of unanchored equipment. The analyses are usually requested in the following areas: 1) seismic response of Transfer Cask in SFP, 2) seismic response of Transfer Cask suspended from the FHB Crane hook while in SFP, 3) stability of Transfer Cask/Storage Cask stack-ups while in FHB during fuel transfer, see Figure 2, 4) seismic stability of the Storage Cask while on the transporter, and 5) seismic response of Storage Cask on the ISFSI pad.

For analyses 1), 3), 4), and 5) the principal input parameters are the contact damping, the contact stiffness, the friction coefficient between surfaces, and the input time histories. Input time histories are developed using guidance of ASCE 4 (2016). For the analysis 2) of the suspended Transfer Cask, the stiffness and damping are not required, and weight is generally not important. It can be verified by the

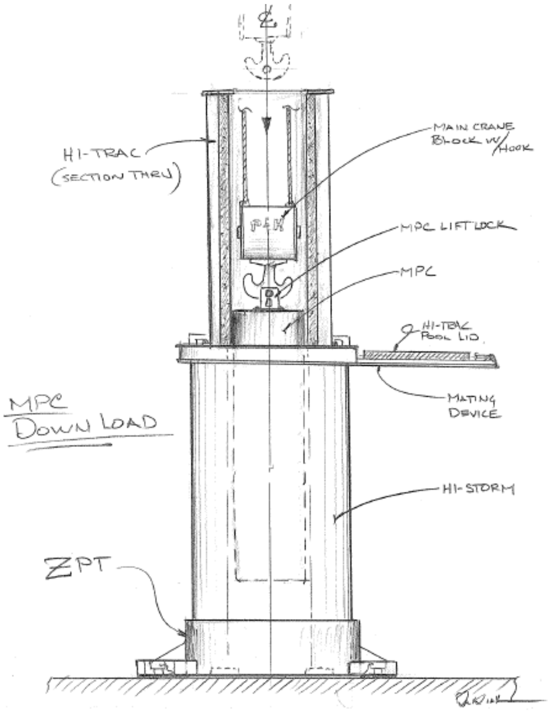

Figure 2. HOLTEC® Stack-Up Fuel Transfer operation (sketched by I.B. Babiak)

frequency equation of the pendulum, where the natural period only depends on the rope's length. However, it is important to recognize that the total displacement of the suspended Cask should be conservatively multiplied by a factor of two to account for the inertial effect during Transfer Cask motion; alternatively, the movement of surrounding walls should be included into the calculation of total displacement.

HIGHER CAPACITY DRY STORAGE SYSTEM

The typical Canister capacities are 68 fuel assemblies for the BWR type of fuel, and 32 fuel assemblies for PWR type of fuel. The typical BWR fuel bundle assembly is about 176 inch long, and 5.5 by 5.5 inches wide, having 10x10=100 fuel rods per bundle, and about 700 lbs of dry weight. The PWR fuel bundle is about 166 inch long, 8.3 by 8.3 inches wide, with 17x17=289 fuel rods, for a total weight of 1540 lbs per bundle.

The higher capacity Canister features 89 and 37 fuel assemblies for BWR and PWR fuels respectively. This upgrade provides (89-68)/68=30 percent more for BWR plants and (37-32)/32 =15 percent more fuel storage for PWR plants. Additionally, newer containers are more advanced, as the technology evolves, and feature higher temperature resistant materials. This way they can accommodate High Burnup fuel which otherwise has to be stored in SFP longer before it is sufficiently cool to be transferred to the dry storage. Major manufacturers are all capable of producing higher capacity storages, among them CASTOR by GNS®, NUHOMS by ORANO®, HI-STORM FW by HOLTEC®, and MAGNASTOR by NAC®. The typical weight distribution across components is shown on Table 2 for BWR fuel type and HI-STORM FW system (shown on Figure 2).

Cumulative weight of Transfer Cask 100s (HI-TRAC®125d) and Storage Cask 100s (HI-STORM ®100S Ver. B) system is 203900 lbs and 346200 lbs respectively, whereas Transfer Cask FW (HI-TRAC® VW) and Storage Cask FW (HI-STORM® FW Version F) is 212300 lbs and 351000 lbs respectively, which is only 4 and 1.3 percent heavier. Additionally, aspect ratios of both systems are nearly identical. Since the conventional load analysis for majority of plants was performed with reasonable conservatism, such margin is usually sufficient to cover such insignificant weight increase, and hence the detailed reanalysis of most plant structures is usually not required.

An exception would be a replacement of some major components during the campaign. For example, a substitution of the wheeled VCT, shown in Figure 1, which weighs around 150000 lbs, with a tracked VCT, which weighs around 282000 lbs, would require a detailed review of Rail Extension Mat, Haul Path, and ISFSI pad including soil subgrade capacity review, seismic analysis, and buried utilities review for increased loads.

Table 2: Comparison between HI-STORM® 100S and HI-STORM® FW systems

Component	**HI-STORM® 100S, 68 Fuel Assemblies, (lbs)**	**HI-STORM® FW, 89 Fuel Assemblies, (lbs)**
Fuel (BWR fuel type, 700 lbs assembly)	700*68=47600	700*89=62300
Basket	16300	12000
MPC Enclosure vessel + lid	21000	23000
Transfer Cask (without a lid)	119000	115000
Water in Water Jacket	9000	9300
Transfer Cask + MPC+ Lifting Ancillaries, w/o water in Water Jacket (shielding feature)	245750	243495
Storage Cask (without a lid)	232300	222700
Storage Cask Lid	29000	31000

Additionally, from Table 2, it can be deduced that total weights of either Transfer Cask, which is 245750 lbs and 243495 lbs for 100S and FW systems respectively, are both close to 250 kips FHB crane capacity limit. This condition strictly prohibits the water in the water jacket, weighting 9000 lbs (100s) and 9300 lbs (FW), during the transfer of fuel within and from SFP to DECON Pad since it can immediately overload the crane.

Lastly, self-weights of HI-STORM® FW system Basket, Transfer Cask and Storage Cask are reduced relative to HI-STORM® 100S system, which is explained by constantly evolving technology and advanced design of the newer system.

HEAVY LIFTING EQUIPMENT/ SINGLE-FAILURE-POOF QUALIFICATION

The conventional practice for the heavy lifting equipment that handles a critical load, is to attain a single-failure-proof qualification. It provides high confidence that no fuel/cask drop, and subsequent release of radioactive material would occur. The NRC through the NUREG-0612 (1980) accepts the design of overhead and gantry cranes, described in ANSI B30.2 (1976), to the stress limits of CMAA-70 (1971). Furthermore, NRC RIS 2005-25 and RIS 2005-25S1 extended acceptance for cranes designed to ASME NOG-1. The NUREG-0554 (1979) expands the qualification to other parts beyond bridge and trolley components.

Fuel Handling Platform (FHP) is a gantry crane that spans SFP and features a telescopic mast with the grapple to handle the fuel. During re-racking, transfer, and storage, at least 7 feet of water above the fuel bundle is required for radiation protection. The SFP Main Fuel Hoist (MFH) is equipped with double reeved wire ropes attached to the mast, as well as dual electrical brakes. The MFH has a capacity of 1100 lbs with a safety factor of 6, which for a double reeved system is equivalent to the safety factor of 12. The grapple has a double hook arrangement designed to close around the fuel bail, such that it precludes the opening mechanically once it is enclosed around the bail. The hoist is considered single-failure-proof, nonetheless Plant's UFSAR still requires performing a Fuel Drop analysis within the SFP, to confirm that the fractured wall of the fuel rack will not result in exceeding the subcriticality level of the stored fuel.

Fuel Handling Building Crane is an overhead bridge crane, supported by the reinforced concrete walls that span the width of the fuel handling area. The main hook has a capacity of 250 kips and together with the crane is qualified to single-failure-proof status in accordance with NUREG-0554 (1979). Such qualification was attained through the rigorous review assessment of crane features and performing a numerous upgrade to crane's essential functions. The crane is designed to perform the entire range of tasks associated with Transfer Cask movement.

Vertical Cask Transporter (VCT), see Figure 1, is used for all lifting, transfer and hauling operations associated with the vertical Storage Cask outside of FHB. The machine is not technically a crane and is also not a special lifting device, hence the qualification of VCT to meet the single-failure proof criteria is attained through conformance to ANSI N14.6 (1993) as well as CMAA-70 (1971), as suggested by NUREG-0612 (1980). The requirements of ANSI N14.6 and of CMAA-70 bound ASME BTH-1 (2005), ASME NOG-1, ASME BPVC Div. I, III, NF (2007) and ASME BPVC Div. I, Section VIII (2007) as shown in Table 3.

Table 3: Lifting Beam Qualification, Normal Operation Loading Case

Design Code	**Normal Stress**	**Shear Stress**	**Shear Stress with Von Misses Stress Factor**	**Load-Path Redundancy Factor**
ANSI N14.6, Section 4.2.1.1	$\sigma_y/3$ $\sigma_u/5$	$\sigma_y/3$ $\sigma_u/5$	$\sigma_y/(3\sqrt{3})$ $\sigma_u/(5\sqrt{3})$	
ANSI N14.6, Section 7.2.1	$\sigma_y/3$ $\sigma_u/5$	$\sigma_y/3$ $\sigma_u/5$		1/2
ASME BTH-1, Design Category B lifters, N_d=3, Sections 3-2.1, 3-2.3.6	$\sigma_y/3$ $\sigma_u/(1.2x3)$	$\sigma_y/3$	$\sigma_y/(3\sqrt{3})$	
ASME NOG-1, Section 4312	$0.5\sigma_y$	$0.4\sigma_y$		1/2
CMAA-70, Section 4.11.4.1	$\sigma_u/5$	$\sigma_u/(5\sqrt{3})$	$\sigma_u/(5\sqrt{3})$	
ASME BPVC, Div. 1, Section III Section NF 3322.1, Level D	$0.6\sigma_y$	$0.4\sigma_y$		1/2
ASME BPVC Division 1, Section VIII	$2\sigma_y/3$	$\sigma_u/3.5$		1/2

Though VCT is Not-Important-To-Safety (NITS) equipment, as defined in NUREG-6407, design requirements for its primary load bearing components are extremely conservative. The recommended von Mises Yield Stress criterion, which comes from the Maximum Distortion Energy Theory, see Hill et (1950), reduces the allowable shear stresses by a factor of 1/sqrt(3). Additionally, ASME BTH-1 and CMAA-70 suggests increasing the applied load by 15 percent to account for the slowly applied lifts.

The factor of 2 is required for special lifting devices without the redundant load path for critical loads, per ANSI N14.6, Section 7.2.1. For example, by defining the VCT lifting beam as a bridge or trolley, and using ANSI N14.6 Section 4 (or CMAA-70), the lifting beam made from A572 Gr. 50 steel with the yielding strength of 50 ksi and ultimate (tensile) strength equal 65 ksi would have normal stresses limited to a minimum of 50 ksi/3= 16.6 ksi, and 65 ksi/5 = 13 ksi or equal 13 ksi, and allowable shear stresses, including von Misses yield stress criterion, equal 65/5/sqrt (3) = 7.5 ksi. Alternatively, defining VCT lifting beam as the special lifting device, and using ANSI N14.6 Section 7, the allowable normal and shear stress would be limited to a minimum of 50/(2x3) = 8.33 ksi, and 65/(2x5) = 6.5 ksi, or equal 6.5 ksi, which are even more restrictive design criteria. Note that ANSI N14.6 does not differentiate between shear and tensile stresses.

In absence of single-failure-proof qualification, the Transfer/Storage Casks drop analysis is required. The maximum lifting height above the ground should be considered for the drop. Site-specific response spectra could be used for the postulated seismic load, otherwise Regulatory Guide 1.60 Response Spectrum is suggested. In absence of real earthquake records the simulated time histories should be generated in accordance with Standard Review Plan 3.7.1 of NUREG-0800.

FLEXIBLE ISFSI PADS

The ISFSI pad under consideration is a rectangular concrete slab, which measures 75 by 347 feet and is 2.5 feet thick located inside of the Protective Area (PA) of the plant. The continuous reinforcement is provided at the top fibers with #8 and 9 rebars spaced at 10 to 12 inches and at the bottom using #11 rebars placed at 10 to 12 inches apart. The concrete minimum compressive strength is specified at 3000 psi, and the minimum yield strength of reinforcing steel is 60 ksi. The subgrade consists of 23 feet of lacustrine, 26 feet of till, followed by the shale. The top couple of feet of soil was replaced by the structural fill. The pad is constructed according to 10 CFR Part 72 license requirements, following guidance of ACI 349 (1985). Soil-Structure Interaction (SSI) and Seismic analyses are required for the accurate evaluation of cask's allowable accelerations, displacement, possibility for tip-over, and for the evaluation of the structural integrity of the pad. The governing Normal operating loading condition is 1.4D + 1.7L, and the Accident/earthquake loading condition is 1.0D + 1.0L+ 1.0S, according to ACI 349 (1985), where D, L, and S are the dead, live and design basis seismic loads respectively. Other requirements are found in NUREG 1536 (1997). ISFSI pads throughout the US are similar in configuration and construction materials, however the thickness and subgrade usually vary.

Bjorkman et al. (2001), found that for less than 4 feet thick pads, the out-of-plane flexibility needs to be considered. The requirement was later added to NUREG 1536 (2010). As such, the structural evaluation review should determine whether the pad under consideration is flexible. If behaviour is observed, the seismic analysis at the minimum should include the response of the pad at the center, and at the edges of the pad. Furthermore, the angular distortions should be reviewed for the full effects of differential settlement. Review of the fully loaded pad (80 cask at 17 feet pitch) using rigid approach and with consideration of flexibility, revealed that the maximum vertical response of casks located near the edge of the pad decreased from 0.1473g (rigid model) to 0.1362g (flexible model), or by 7 percent; whereas for casks in the middle, it increased from 0.1273g (rigid model) to 0.1465g (flexible case) or by 15 percent. This effect indicated that neglecting the pad flexibility leads to underestimation of seismic load effects. Other configurations, such as half-pad loaded cases, or pads loaded with various types of cask models, should be evaluated on a case-by-case basis, specifically for angular distortions. The pad deflection was estimated to be equal 2.19 inches in the middle of the pad (against allowable of 3 inches), and 0.57 inch at the corners, which resulted in the angular distortion of (2.19-0.57)/12/75/2 =0.0009, which is below the allowable of 0.007, at which moderate cracking can occur. Such analyses can be performed using commercial software such as, ACS-SASSI®, SuperSassi®, and LS-DYNA®. Modelling details of some storage containers can be found in Nizamiev (2019).

MARGINS OF SAFETY

The summary from some analyses, related to capacity of FHB structures, Haul Path, and ISFSI pad were reviewed in Table 4. Except for Haul Path, which includes Turning and Bridging Slab, reported analyses include design basis seismic load. Typically, these analyses feature a significant conservatism in application of loads, combination of responses, and estimation of floor structural capacity. The stack-up weight on the floor of Rail Bay area is the most demanding load case, for which the ANSYS® model included the load bearing capacity of slab-supporting caissons, and hence the reported safety margins include combined capacity of the floor.

Table 4: Safety Margins in Capacity of FHB, Haul Path and ISFSI pad

Location	Capacity	Load	Margin	Notes
Spent Fuel Pit	754	444	59 %	Bending Moment (ft-kip/ft)
	122	108	89 %	Shear (kip/ft)
	30	7.96	26 %	Soil Bearing Pressure (ksf)
SFP Intermediate Platform	650	425	65 %	Bending Moment (ft-kip/ft)
	102	95	93 %	Shear (kip/ft)
	18	8.9	49 %	Sliding Displacement (in)
DECON Pad	239	102	43 %	Bending Moment (ft-kip/ft)
	48	39	81 %	Shear (kip/ft)
	14	1.85	13 %	Sliding Displacement (in)
Stack Up* in Rail Bay (Figure 2)	18	1.194	6.6 %	Tip-Over, Degrees
	36	8.76	24 %	Displacement (in)
	-	-	46 %	Bending Moment (ft-kip/ft)
	-	-	84 %	Shear (kip/ft)
Caisson	2003	1128	56 %	Axial Load (kips)
Haul Path	72.4	51.1	70 %	Bending Moment (ft-kip/ft)
	21.7	18.1	83 %	Shear (kip/ft)
	305	135	44 %	Punching Shear (kip)
ISFSI Pad	108	77.3	72 %	Bending Moment (ft-kip/ft)
	28	22.1	79 %	Shear (kip/ft)
	2317	743	32 %	Punching Shear (kip)
FHB Crane	250	244	98 %	Max Lifting Weight (kip)
Fuel Handler/Grapple	1100	700	63 %	Lifting/Bundle Weight (lbs)
VCT, Lifting Beam	45	36.1	80 %	Normal Stress (ksi)
	25	14.5	58 %	Shear Stress (ksi)
Haul Path, (SF=3)	4	2.36	59 %	Subgrade Capacity (ksf)
ISFSI Pad, (SF=2)	2.5	0.47	18.7 %	Subgrade Capacity (ksf)
Cask Tip-Over	45	39.1	87 %	Deceleration, (g)
Cask End Drop	45	44.4	98.6 %	Deceleration, (g)
Thermal Load/Fire	1058	714	67 %	Fuel Cladding Temp (°F)
	1100	1413	Fail*	Overpack Concrete (°F)

Lifting margin of FHB crane is taken against the weight of the loaded Transfer Cask, whereas capacity of the Fuel Handler/Grapple, located on FHP, is taken with respect to the maximum weight of BWR fuel assembly.

The normal and shear stresses on the VCT lifting beam are reported for the case then VCT is subjected to a total weight of 360 kips lifted at 14.5 inch high and subjected to 4% Damping of Regulatory Guide 1.60 spectrum seismic load which bounds site-specific seismic load. The design weight of VCT used in Haul Path, ISFSI and subgrade analyses was calculated as, Storage Cask Weight + VCT Weight + 20% impact factor = (395 kips + 143 kips) x 1.2 = 646 kips, which is equivalent to 41 kips (16 wheels) for each wheel load. The deceleration limits are always specified in Dry Storage System FSAR, and essentially limit the accelerations the cask get due to postulated tip-over accident and accidental drop from 11 inches height on ISFSI pad. Due to continuously evolving design, the newer generation of Storage Cask also improve the deceleration limits.

The thermal load due to fire on VCT is very conservatively estimated, for instance, the ignition of all 16 wheels, a whole tank of diesel, as well as all hydraulic fluids occur simultaneously. However, during the fire, the fuel is still safely stored; the exceeded safety margin on the overpack indicated, that the local damage to concrete, such as spalling, would occur.

CONCLUSION

The qualification of Plant facilities to loads imposed by the installation of higher capacity units indicated, that the increase in overall stresses due to weight of the equipment is not significant, and hence the detailed re-evaluation of facilities margin is generally not required. In many cases, the stresses are decreased. Provided safety margins on loads due to installation of the system, demonstrated that the design of principal components is generally adequate and conservative.

However, there are several engineering issues, that require a specific expertise in topics such as flexibility of ISFSI pad, an evaluation of single-failure-proof-criteria for cranes, an evaluation of seismic stability of unanchored equipment, SSI analyses and others. Hence, an installation or transition to the higher capacity storage systems is highly advisable and recommended, provided the reasonable engineering review is performed.

It is also observed that the ISFSI pad is somewhat underutilized. The review of applied loads indicated that there is enough structural capacity for the slab to support more casks per given area. In practice however, the pitch between the storage casks is chosen such that to fit the cask movers, similar to VCT.

By switching to the higher capacity storage system with 89 fuel bundles per Cask, this Plant effectively expanded the available storage to fit 1155 more spent fuel assemblies on the existing pad, which is equivalent to 1155/68 = 17 Casks with 68 fuel bundle capacity of otherwise unused space. Additionally, since the typical campaign unloads about 4 containers every two years per reactor, it provides about eight years of time extension for utilization of the pad, before it reaches its full capacity.

REFERENCES

Title 10 CFR Part 50." Domestic Licensing of Production and Utilization Facilities", Code of Federal Regulations

Title 10 CFR Part 72. "Licensing Requirements for the Independent Storage of Spent Nuclear Fuel, High-Level Radioactive Waste, and Reactor-Related Greater Than Class C Waste", Code of Federal Regulations

Title 10 CFR Part 20. "Standards for Protection against Radiation", Code of Federal Regulations

Title 10 CFR Part 100. “Reactor Site Criteria”, Code of Federal Regulations

NUREG-1536 (1997). “Standard Review Plan for Dry Cask Storage Systems”, US Nuclear Regulatory Commission, Revision 0

NUREG-1567(2000). “Standard Review Plan for Spent Fuel Dry Storage Facilities”, US Nuclear Regulatory Commission

NUREG-2215 (2020). “Standard Review Plan for Spent Fuel Dry Storage Systems and Facilities-Final Report”, US Nuclear Regulatory Commission

NUREG-0800, SRP 3.7.1 (2014).” Seismic Design Parameters”, Revision 4, US Nuclear Regulatory Commission

ACI-349 (2013). “Code Requirements for Nuclear Safety Related Concrete Structures”, American Concrete Institute

ASCE-4 (2016). “Seismic Analysis of Safety-Related Nuclear Structures”, American Society of Civil Engineers

NRC RIS 2005-25, Supplement 1, “Clarification of NRC Guidelines for Control of Heavy Loads”, US Nuclear Regulatory Commission

ASCE/SEI 43 (2005).” Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities”, American Society of Civil Engineers

Hill R., (1950).” The Mathematical Theory of Plasticity”, Oxford Press, Oxford

ANSI B30.2 (1976).” Overhead and Gantry Cranes (Top Running Bridge, Single or Multiple Girder, Top Running Trolley Hoist”, American National Standards Institute

NUREG-0612 (1980).” Control of Heavy Loads at Nuclear Power Plants”, US Nuclear Regulatory Commission

NUREG-0554 (1979).” Single-Failure Proof Cranes for Nuclear Power Plants”, US Nuclear Regulatory Commission

ANSI N14.6 (1993).” Special Lifting Devices for Shipping Containers Weighing 10000 Pounds (4500 kg) or More”, American National Standards Institute

CMAA-70 (1971).” Specification for Electric Overhead Traveling Cranes”, Crane Manufactures Association of America, Inc

ASME BTH-1 (2005). “Design of Below-the-Hook Lifting Devices”, American Society of Mechanical Engineers

ASME NOG-1. “Rules for Construction of Overhead and Gantry Cranes”, American Society of Mechanical Engineers

ASME BPVC Division I, Section III, Subsection NF (2007). “Rules for Construction of Nuclear Power Plant Components, Supports”, American Society of Mechanical Engineers

ASME BPVC Division I, Section VIII (2007).” Rules for Construction of Pressure Vessels” American Society of Mechanical Engineers

NUREG-6407 (1996).” Classification of Transportation Packaging and Dry Spent Fuel Storage System Components According to Importance to Safety”, US Nuclear Regulatory Commission

US NRC REG GUIDE 1.60 (2014). “Design Response Spectra for Seismic Design of Nuclear Power Plants”, US Nuclear Regulatory Commission, Revision 2

US NRC REG GUIDE 1.13 (2007).” Spent Fuel Storage Facility Design Basis”, US Nuclear Regulatory Commission, Revision 2

ANSYS Program, User Guide, Current Version

LS-DYNA Program, User Guide, Current Version

SuperSassi Program, User Guide, Version 2.0

ACS-SASSI Program, User Guide, Current Version

Bjorkman G.S. and Moore D.P. (2001).” Influence of ISFSI Design Parameters on the Seismic Response of Dry Storage Casks, “SMIRT-16 Transactions, Washington, D.C, USA

Nizamiev K., Papadelis C., and Wilson. P (2019).” Structural Qualification of ISFSI Pad to NUHOM MATRIX Dry Storage Assembly Installation, SMIRT-25 Transactions, Charlotte, NC, USA