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**SUBMITTAL OF COMMITMENT RESOLUTION**
**LETTER #19 INFORMATION**
**DOCKET NO. 72-22 / TAC NO. L22462**
**PRIVATE FUEL STORAGE FACILITY**
**PRIVATE FUEL STORAGE L.L.C.**

In accordance with our October 4, 1999 conference call, Private Fuel Storage (PFS) submits the following resolution to NRC/CNWRA questions and comments regarding the cask storage pad sliding analysis for the Private Fuel Storage Facility (PFSF).

**NRC Questions and Comments**

- The NRC questioned the use of soil cohesion at the concrete-soil interface to resist the sliding force and how it would be achieved during pad construction.
- The NRC suggested a positive locking mechanism, such as a key, be considered to resist sliding.

**PFS Response**

The PFS response to the above questions/comments is enclosed. If you have any questions regarding this response, please contact me at 303-741-7009.

Sincerely

John L. Donnell
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Enclosure

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# PFS ADDITIONAL INFORMATION
# CASK STORAGE PAD SLIDING STABILITY

## NRC Comments

The following additional information regarding the cask storage pad sliding stability is provided in response to a teleconference held on October 4, 1999 between PFS and NRC.

The discussion was a result of the NRC review of the Private Fuel Storage Facility (PFSF) license application submittal (Amendment 6) and the design information provided by PFS for the sliding stability of the cask storage pads during a design basis seismic event. The NRC questioned whether the use of soil cohesion at the concrete-soil interface to resist the sliding force was in agreement with standard geotechnical practice, citing pages 328 and 329 of Terzaghi, Peck, and Mesri (1996). The NRC asked what was the mechanism that allowed for the use of cohesion at the interface and how would it be achieved during pad construction. The NRC suggested a positive locking mechanism, such as a key, be considered to resist sliding.

PFS responded that cohesion is an acceptable means to resist sliding in cohesive soils, as discussed in many other soil mechanics textbooks. PFS committed to evaluate the NRC comments and review the textbook references for the use of cohesion to resist sliding.

## Response

Following the teleconference, the first step taken by PFS was to review the textbook referenced by the NRC (Terzaghi, Peck, and Mesri, 1996). Regarding the safety against sliding of retaining walls, this textbook states:

> *"If the wall rests on silt or clay, special precautions are required. Immediately before the footing is cast, the soil, to a depth of about 0.1 m, should be removed over the area to be covered by concrete and replaced by 0.1 m layer of well compacted sharp-grained sand or sand and gravel. The value of $\phi$ between the sand and the underlying soil can be assumed as 20°. However, if the undrained shear strength $s_u$ of the underlying soil is less than the frictional resistance beneath any part of the base, the slip will take place by shear in the soil at some distance below the base."*

The context of the recommendation to install a 0.1 m layer of well compacted sharp-grained sand or sand and gravel appears to be aimed at providing a level and stable working surface for forming the footing and for concrete placement upon "soft" soils, since it does not contribute to structural support. It is obvious that, in this case, the cohesionless layer would interfere with the transmission of sliding forces directly to the underlying cohesive silt or clay soil. Since granular materials have no cohesion, the sliding resistance is based on their friction angle and the normal load. PFS has chosen to take advantage of the cohesive nature of the in situ soils and avoid placement of the

cohesionless granular base course. The surface layer above the clayey soils was to be removed and used for berm construction. Immediately after excavation, a 4" thick concrete mudmat was to be placed to protect the surface of the clayey soil from disturbance and maintain its cohesion to resist sliding. The proposed construction details are shown on SAR Figure 4.2-7.

Second, PFS performed a review of other soil mechanics textbooks and references to confirm the acceptability of using cohesion along the base of the foundation to resist sliding. Results show the approach used by PFS is consistent with what is reported in the following references:

- Regarding base shear for buildings supported on mat foundations, page 328 of Zeevaert (1972) indicates:

  *"...the shear strength parameters should be determined by means of unconsolidated undrained tests, from which the average shear strength at the foundation grade elevation is:*

  $$s_{cu} = c_{cu} + \frac{W}{A}\tan\phi_{cu}$$

  *in which A is the foundation area and W is the total weight of the building."*

- Regarding base shear for resisting sliding of gravity walls, page 386 of Tschebotarioff (1973) indicates:

  *"For clay soils the shearing resistance along plane 1-2 of the base can be taken to equal one-half of the unconfined compressive strength $q_u$ of the clay."*

- Page 639 of McCarthy (1998) states: $R = \mu (W + P_v) + cB$

  Where:
  R = resistance to sliding
  $\mu$ = coefficient of friction between wall and foundation
  W = weight of wall
  $P_v$ = vertical force acting on wall due to backfill
  c = cohesion of foundation soil
  B = width of base of wall.

- Page 426 of Peck, Hanson, and Thornburn (1974):

  *"If the base of the retaining wall rests on clay, the shearing resistance against sliding should be based on the cohesion of the clay, which can be conservatively estimated as one-half the unconfined compressive strength. If the clay is stiff or hard, its surface should be roughened before the concrete base is placed."*

- Page 321 of Teng (1962):

  *"In computing the sliding stability of retaining walls on cohesive soils the adhesion between the base slab and the soil is assumed to be equal to the cohesive strength of the clay and $\phi$ is assumed to be zero. If the clay is stiff or hard, the ground must be roughened before placing concrete to insure the full adhesion."*

- Page 7.2-63 (Table 1) of NAVFAC (1986):

  For foundations established on cohesive soils, Table 1 provides representative adhesion ($C_a$) values for sliding resistance at the foundation base. The $C_a$ value is based on the cohesion of the interface material.

The integrity of the silty clay subgrade will be protected during construction, therefore, PFS has used cohesion to resist sliding on Page 14 of Calculation 05996.02-G(B)-04, Rev 4, "Stability Analyses of Storage Pads". The analyses are discussed in SAR Section 2.6.1.12.1 under the section titled "Sliding Stability of the Cask Storage Pads". As indicated in the SAR, the total strength ($c = 1.22$ ksf and $\phi = 24.9^\circ$) available to resist sliding was measured in direct shear tests on samples of the clayey silt obtained in the pad emplacement area (Sample U-1 in Boring C-2). These direct shear test results are included in Attachment 7 of Appendix 2A of the SAR and are consistent with the results obtained from testing samples obtained of these clayey soils under the Canister Transfer Building.

Third, PFS evaluated the use of shear keys to provide additional margin for resistance to sliding. The option was previously reviewed during the storage pad design phase and found to be unacceptable because of the cask vendor's impact analyses for cask drop and tipover. The cask vendor has strict criteria for the storage pad target hardness that assures it is a yielding surface to limit the impact forces imparted to the spent fuel canister. The pad thickness is a critical characteristic in the pad hardness and the effects of stiffening the pad by the use of shear keys has not been evaluated by the cask vendors.

**Additional Discussion**

The questions raised by the NRC caused the PFS to review the proposed methods for resisting sliding under seismic load conditions for the cask storage pads. The review was timely in that PFS was also evaluating the site grading, earthwork, and imported fill requirements as part of the NRC questions derived from the review of the PFS Environmental Report.

A major factor in the earthwork required for construction of the facility is the surficial layer of eolian silt that exists across the entire site, as identified by Geomatrix (1999). The average thickness of this layer is approximately 3 feet. This material is generally a nonplastic to slightly plastic silt that was planned for removal prior to storage pad construction. However, as a result of the recent overall review, PFS has decided to

stabilize this soil with cement and use it as base material beneath the storage pads and adjacent driveways. This approach will reduce the amount of spoil materials generated, create a stable and level base for pad construction, and substantially improve the sliding resistance provided for the storage pads.

The soil-cement will be placed above the in-situ clayey layer and will be designed to improve the strength of the eolian silt so that it will be stronger than the clayey soils that were originally intended for use as the founding medium for the pads. The soil-cement will also be designed and placed to provide an improved margin of safety against a sliding failure. The reader is referred to the "State-of-the-Art Report on Soil Cement" (ACI, 1998) for additional information about soil cement, including applications, materials, properties, mix proportioning, design, construction, and quality-control inspection and testing techniques. The design, placement, testing and performance of soil-cement is a well-established technology and has been used extensively in the United States since the 1940's.

The strength of soils can be improved markedly by the addition of cement. The eolian silts at the site are similar to the soils identified as Soil A-4 in Nussbaum and Colley (1971) and Soils No. 7 and 8 in Balmer (1958). As indicated in Table 5 for Soil A-4, Nussbaum and Colley (1971), the addition of just 2.5% cement by weight to the silt increases the cohesion from 5 psi (720 psf) to 30 psi (4,320 psf). The cohesion for Soils No. 7 and 8 were also increased significantly by the addition of low percentages of cement, as shown on Tables VI and VII in Balmer (1958). Soil 4 in Felt and Abrams (1957) is also similar to the eolian silts at the site. Figure 10 in Felt and Abrams (1957) illustrates the continued strength increase over time for these soil-cement mixtures. Other examples of soil-cement strength increases over time are presented in Figure 4.3 of ACI (1998), Table 6 of Nussbaum and Colley (1971), and Figures 6 and 7 of Dupas and Pecker (1976). Therefore, the soil-cement will be much stronger than the underlying clayey soils and their strength will increase with time. The soil-cement will provide an improved foundation material and will provide an additional margin against sliding compared to constructing the pads without the proposed soil-cement layer.

The minimum cohesion (shear resistance) required at the pad foundation base and within the underlying soil materials to resist sliding for the seismic load cases is approximately 8.5 psi, as determined by Calculation 05996.02-G(B)-04, Rev. 4. Adequate sliding resistance can be provided by the cask storage pads being placed directly on a properly designed and installed soil-cement subgrade. Shear resistance will be provided primarily by the bond and friction established at the pad foundation and soil cement contact. Shear resistance will also be transferred through the approximately three-foot thick soil-cement layer and into the underlying clay subgrade. With the soil-cement design, the shear resistance requirements within the in-situ clay layer will be less than required with the previous design.

The critical shear resistance for seismic load transfer will most likely be controlled by the shear resistance at the foundation contact and at soil-cement lift contacts, as discussed in DeRoot (1976). The shear strength along soil-cement lifts is generally less than the shear

strength through the soil-cement. Strong bonds however exist between soil-cement lifts and with concrete contacts, due to the roughened contact and hydration process that occurs in soil-cement. Discussions with Wayne Hadaska, a soil-cement expert at PCA and chairman of the committee for the "State-of-the-Art Report on Soil Cement" (ACI 1998), indicates that a shear resistance in excess of 8.5 psi can be obtained at the lift contacts and at the concrete/soil-cement contacts, for low percentage cement mix designs.

PFS proposes to stabilize all of the eolian silts near the surface within the pad emplacement areas with soil-cement. The soil-cement layer will be approximately 3-ft thick under the pads and in the areas between the pads. PFS also proposes to replace some of the structural fill shown in the section between the rows of pads in SAR Figure 4.5-6 with soil-cement. This continuous layer of soil-cement under and between the pads will perform like a mat to spread the loads from the pads beyond the footprint of the pads and will help reduce the predicted total and differential settlements of the pads. The bond and friction between the pad foundation and the underlying soil-cement layer will provide the necessary sliding resistance required.

PFS has discussed the change to use soil-cement beneath the storage pads with the project consultants who have analyses in-place that are based on the storage pads resting on the clayey soil layer. The consultants contacted were Geomatrix (development of seismic criteria and soil dynamic properties), Holtec International (cask stability analysis), and International Civil engineering Consultants (pad design). Each has indicated their analyses would not be adversely affected by this proposed change.

The following describes the processes that will be used to develop a proper soil-cement mix design and establish adequate sliding resistance at each material interface in the storage pad and soil system:

- Soil-Cement Mix and Procedure Development – The sliding force resulting from seismic activity that excites the casks and pad will be resisted by a combination of friction and bond between the foundation and soil-cement. The soil-cement mix will be designed and constructed to exceed the minimum shear resistance requirements. During the soil-cement design phase, laboratory direct shear testing will be conducted along manufactured soil-cement lift contacts and concrete contacts that represent anticipated field conditions. The direct shear testing, along with other standard soil-cement testing will be used to confirm that adequate shear resistance and other strength requirements will be provided by the final soil-cement mix design. Procedures required for placement and treatment of the soil-cement, lift surfaces, and foundation contact will be established during the mix design and testing process. Specific construction techniques and field quality control requirements will be identified in the construction specifications developed by PFS during this detailed design phase of the project.

- Soil-Cement Lift and Concrete Interface – The soil-cement will be constructed in lifts approximately 6-in thick (compacted thickness) as described in ACI (1998). Construction techniques will be used to ensure that the interface between the soil-

cement layers will be adequately bonded to transmit shear stresses. Techniques described in Section 6.2.2.5 of ACI (1998) will include, but will not be limited to: minimizing the time between placement of successive layers of soil-cement; moisture conditioning required for proper curing prior to placement of succeeding layers or concrete foundations; and producing a roughened surface on the soil-cement prior to placement of additional lifts or concrete foundations. In addition to conventional quality controls testing performed for soil-cement projects, direct shear testing will be performed on representative samples obtained from placed lift contacts to confirm design requirements are obtained. Sacrificial soil-cement lifts may be used to protect the soil-cement subgrade in the pad foundation areas.

- Soil-Cement and In-Situ Clay Interface – The soil-cement and in-situ clay interface will be constructed such that a good bond will be established between the two materials. Construction techniques will be utilized that will ensure the integrity of the upper surface of the clay is maintained and that a good interface bond between the two materials is obtained. The surface of the clay layer will properly moisture conditioned, compacted and the surface roughened just prior to placement of the fist soil-cement lift. Specific construction techniques and field quality control requirements will be identified in the construction specifications developed by PFS during the detailed design phase of the project.

An additional benefit of incorporating the soil-cement into the design is that it will minimize the environmental impacts of constructing the facility. Using on-site materials to construct the soil-cement, rather than excavating and spoiling those materials will reduce environmental impacts of the project. In addition, replacement of some of the structural fill layer between the rows of pads, as shown in SAR Figure 4.5-6, with soil-cement will result in a net reduction of trucking requirements associated with transporting materials to the site.

**References:**


1. ACI (1998), "State-of-the Art Report on Soil Cement," reported by ACI Committee 230, ACI 230-1R-90 (Reapproved 1997), American Concrete Institute, Detroit, MI.
2. Balmer, G.G., "Shear Strength and Elastic Properties of Soil-cement Mixtures Under Triaxial Loading", Portland Cement Association, Bulletin No. D 32, 1958.
3. DeGroot, G., "Bonding Study on Layered Soil Cement", REC-ERC-76-16, U.S. Bureau of Reclamation, September 1976.
4. Design Manual 7.02, "Foundations & Earth Structures," NAVFAC, Alexandria, VA, September 1986.
5. Dupas, J., and Pecker, A., "Static and Dynamic Properties of Sand-Cement," *Proceedings ASCE*, JGED, Vol. 105, GT 3, March 1979, pp 419-436.
6. Felt, E.J. and Abrams, M.S., "Strength and Elastic Properties of Compacted Soil-Cement Mixtures, Portland Cement Association, Bulletin No. D 16, 1957.
7. Geomatrix Consultants, Inc., 1999, "Fault Evaluation Study and Seismic Hazard Assessment Study - Final Report", prepared for Stone and Webster Engineering Corp., Denver, CO, 3 volumes.

8. McCarthy, D. F, *Essentials of Soil Mechanics and Foundations, Basic Geotechnics*, Prentice-Hall, Inc, Upper Saddle River, NJ, 1998.
9. Nussbaum, P. J., and Colley, B. E., *Dam Construction and Facing with Soil-Cement*, Portland Cement Association Publication RD010.01W, 1971.
10. Peck, R. B., Hanson, W. E., and Thornburn, T. H., *Foundation Engineering*, John Wiley & Sons, New York, NY, 1974.
11. Teng, W. C., *Foundation Design*, Prentice-Hall, Inc, Englewood Cliffs, NJ, 1962.
12. Terzaghi, K., Peck, R. B., Mesri, G., *Soil Mechanics in Engineering Practice*, John Wiley & Sons, New York, NY, 1996.
13. Tschebotarioff, G. P., *Foundations, Retaining and Earth Structures*, McGraw-Hill, New York, NY, 1973.
14. Zeevaert, L., *Foundation Engineering for Difficult Subsoil Conditions*, Van Nostrand Reinhold Co, New York, NY, 1972.