J. Lombardo

UNITED STATES
NUCLEAR REGULATORY COMMISSION
WASHINGTON, D. C. 20555

JUN 26 1984

MEMORANDUM FOR: Gus C. Lainas, Assistant Director
for Operating Reactors
Division of Licensing

Thomas Novack, Assistant Director
for Licensing
Division of Licensing

FROM: James P. Knight, Assistant Director
for Components & Structures Engineering
Division of Engineering

SUBJECT: EVALUATION OF SPENT FUEL RERACK DESIGNS

Attached is a schedule of work for the licensing amendments pertaining to operating reactor spent fuel rerack design. The proposed target dates will not be met because of the following reasons:

1. Sang Bo Kim, SGEB's spent fuel rerack reviewer, was detailed to the Waterford Task Force. Consequently, the review work was contracted out to the Franklin Research Center (FRC), thereby requiring time for their familiarization with the regulatory requirements.

2. FRC has found an error in the Oyster Creek (J. Oat) rack response analysis method. Resolution of this problem will require more time (and possibly funds) than anticipated for an uncomplicated review. Also, there is a possibility that additional issues will be identified as this review progresses.

3. Information from the licensees, through DL project management, has not been always expedited as much as it should have been.

The staff is currently working with FRC to be able to meet schedule requirements. We are also attempting to obtain the service of a recognized expert in non-linear dynamic analyses to augment FRC effort. In this regard, assistance provided to us by Mr. M. Carrington in contracting matters has been prompt, very helful, and appreciated.

New target dates will be developed in the near future in concern with DL-PMs, M. Carrington and FRC. We will keep you advised promptly.

cc: See next page.

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George Lear
for James P. Knight, Assistant Director
for Components & Structures Engineering
Division of Engineering

Enclosure: As stated

cc: J. Lombardo D. Crutchfield
J. Hopkins S. Kim
L. Birkle M. Carrington
D. Sells H. Polk
G. Dick G. Lear
D. McDonald P. Kuo
E. Adensam

STRUCTURAL AND GEOTECHNICAL ENGINEERING BRANCH
SPENT FUEL RACK DESIGN REVIEW SCHEDULE

TAC #	TITLE	TARGET DATE	FRC INPUT	DL-PM	PHONE NO.	VENDOR
48787	Oyster Creek	6/1/84	5/25/84	Jim Lombardo	27167	Joseph Oat
53317	Summer	6/18/84	6/10	Hopkins		Joseph Oat
53531/2	McGuire 1&2	6/30/84	6/20	L. Birkle	28408	W
54463	St. Lucie 2	8/1/84	7/20	D. Sells	29735	CE
54762	Ginna	9/1/84		G. Dick	27215	US to W
54480/1	Turkey Pt. 3&4	9/15/84	8/20	D. McDonald	27363	W

June 29, 1984

Mr. Robert L. Lorenzo
GPU Nuclear
100 Interpace Parkway
Parsippany, NJ 07054

Dear Mr. Lorenzo:

The goal of resolving outstanding questions on the Oyster Creek reracking submittal made significant headway in the meeting at the NRC on June 27, 1984, attended by personnel from the NRC, FRC, GPU and Oat. The only remaining substantive issue pertains to the time step used in the solution procedure. This matter would have been resolved too, had we had the benefit Mr. George Lear's presence. Mr. Kim advised us that he will refer the matter to your attention to develop the commission's position in this matter. Since much of what I presented at the meeting on this subject is not documented anywhere, I thought that it would be prudent to summarize the facts for your review.

The three-dimensional seismic analysis of the high density racks is carried out using the direct time history method. In this method, the rack is idealized as a multiple degree of freedom structure (32 degree of freedom in our model); and the equations of motion for each degree of freedom are sequentially written. These equations of motion are second order ordinary differential equations in the time coordinate. Oat's computer program DYNAHIS solves these equations using the classical numerical solution scheme, known as the "central difference method". In essence, this method entails approximating the second derivative of the generalized coordinate x at the instant t_n, by the equation:

$$\frac{d^2x}{dt^2} = \frac{x_{n+1} - 2x_n + x_{n-1}}{(\Delta t)^2} \qquad (1)$$

In the above x_n is the instantaneous value of x at the instant in time; x_n-1 and $x_n + 1$ are the values at the preceding time instant ($t_n-\Delta t$) and the succeeding time instant ($t_n + \Delta t$), respectively. Δt is the "time step". Central difference is one of the most widely used integration schemes; also one of the most widely analyzed. It, like all numerical simulation schemes, has certain attributes. Some of its intrinsic characteristics are particularly important to our understanding of Oat's time history analysis; and therefore warrant elaboration. It is perhaps most conveniently presented by considering a simple harmonic oscillator of Figure 1. The natural vibration equation of motion is

$$mx + kv = 0 \qquad (2)$$

and the resulting exact solution is

$$x = A \sin wt + BCOS\ wt \qquad (3)$$

where A and B represent the "amplitude" and w is the circular frequency.

$$w = (k/m)^{1/2} \qquad (4)$$

The central difference solution of Eq. (2) will be considered "good" if it also gives a "time invariant amplitude", and comes out with the value of the circular frequency close to m. The only latitude available to the analyst is the size of the time step. Solutions for two values of selected time steps - one small, one large, tell the crux of the story.

(a) Let $\Delta t = 1.414/w$

The resulting solution is $x = A \sin 1.11\ wt + B\ OS\ 1.11\ wt$

(b) Let $\Delta t = 3/2$ then the solution is

$x = [A\ snh\ .624\ wt]\ 5\ in\ 1.047\ wt\ t\ [B \cosh .624\ wt] \sin 1.047\ wt$

The following observations are important:

(i) The small time step solution does have a time invariant amplitude; the frequency is reasonably close (1.11w vs. w).

(ii) The large amplitude solution has time independent amplitude terms - an unacceptable solution. In fact, the amplitude terms A sinh .624 wt will inevitably become large - "blow up" in the computer lingo - with increasing t.

Further study into the characteristics of the central difference solution reveals that there is a stability boundary for acceptable time step size. If the time step size exceeds this threshold than the solution will "diverge" - they will be unreliable. Indeed, the required time step size is inversely proportional to the natural frequency of the system. An extremely stiff rack system requires an extremely small time step. Oat's racks are known to be the most rigid ones available in the industry. Consequently, the required time step is very small; in the order of 2×10^{-5} secs!!

Returning to the simple oscillator for a moment, Table 1 gives the exact solution. We note that:

Table 1

t	Δt	Δt = .5	Exact Solution
0	0	0	0
1.0	1.	.875	0.841
2.0	1.	0.926	0.909
3.0	0	0.106	0.141
4.0	-1	-.815	-.757
5.0	-1	-.975	-.959

The central difference solution in both cases approaches the exact solution from up above - a very desirable attribute in nuclear plant analyses where an upper bound solution clearly serves the goals on safety.

The neatly derivable effects of time step on the central difference solution cannot be expected to carry over entirely to the solution of a highly non-linear structural model, such as the rack system. Yet, there is a striking parallel between them. Table 2 shows the effect of Δt on the solution outcome for rack F in the GPU pool (rack F has been studies most intensively in the last month at the behest of the Franklin people).

Table 2
Effect of Δt on the calculated maximum rack corner displacement.

Time Step (sec)	Maximum Corner Displacement (inch)
0.4×10^{-4}	blows up @ .0059 sec.
0.35×10^{-4}	blows up @ .131 sec.
$.325 \times 10^{-4}$	blows up @ .0799 sec.
0.3×10^{-4}	1.298" @ 13.73 sec.
0.2×10^{-4}	0.17" @ 5 sec.

We note that the larger the time step, the faster the solution blows up (blow up defined as 3" of corner displacement). The solution of $.3 \times 10^{-4}$ sec. seems to indicate large displacements towards the end of the earthquake (at 13.73 sec.) - the behavior identical to the one found in the simple oscillator when Δt is not small enough (diverging solution). Smaller Δt (.00002 sec.) gives the maximum solution at around 5 secs. into the earthquake - a telltale sign of a stabilized solution. (Diverging solutions show peak results towards the end of the earthquake).

The above trend study establishes the 0.00002 sec. time step as the most acceptable input data. While we cannot claim a specific degree of accuracy associated with this time step, we can reasonably ascribe to it a degree of previously mentioned conservatism intrinsic to the central difference solution.

Unfortunately, the limitations imposed by the word length carried by the computer limit us to using much smaller time steps. This keeps us from carrying the "trend studies" to the end. But we believe that the amount of information already garnered would satisfy most practical analysts.

However, to instill further confidence, Oat was instructed to run rack F for 10 secs. of earthquake with some of the easily removable assumptions removed. Rack F is being rerun for one vertical and one horizontal earthquake applied along the weak direction with the following changes; 4% structural damping based on 7 cps natural frequency, form drag on fuel assembly only using the lower bound drag coefficient of 0.6, fuel assembly movement to storage location gap set equal to the design value of 0.25" all around. This run, due to be completed by July 1, 1984, will show (we expect) that actual displacements are an order of magnitude smaller. Mr. Clyde Herrick of FRC has predicted it all along; we believe the analysis will prove him right.

We trust that the above information will help your decision making process.

Very truly yours,

R. L. Laengo for K. P. Singh

K. P. Singh
Joseph Oat
Vice President - Engineering