

CONF-851115--31

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Concrete Building Calculations

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TI86 002187

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Presented at the Annual Meeting of the
American Nuclear Society
San Francisco, California
November 10-14, 1985

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**Operated by Martin Marietta Energy Systems, Inc. under contracts with
the Containment Systems Research Branch of the Office of Nuclear Regulatory
Research, U. S. Nuclear Regulatory Commission under Interagency Agreements
DOE 40-551-75 and 40-552-75 and Contract DE-AC05-84OR21400 for the U. S.
Department of Energy.

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The Extension of the Linear Nodal Method to Large Concrete Building Calculations

R. L. Childs W. A. Rhoades

Studies of radiation penetration into large concrete and masonry structures are in progress at Oak Ridge National Laboratory. Accomplishments to date include the development of TORT¹, a 3-d extension of the DOT² discrete ordinates transport code, and the completion of an experiment at the Tower Shielding Facility for methods testing purposes. In this paper, the implementation of the linear nodal method³ in the TORT code is described, and the results of a mesh refinement study to test the effectiveness of the linear nodal and weighted diamond difference methods² available in TORT are presented.

The linear nodal method for the solution of the discrete ordinates form of the transport equation for 2-d Cartesian systems was reported by Walters and O'Dell³ in 1981. In a recent paper Walters⁴ outlined the derivation of an augmented weighted diamond form of the linear nodal equations in 3-d Cartesian co-ordinates and implemented these equations in 2-d. Walters makes one approximation in his derivation which allows him to obtain a much less complex formulation with little loss of accuracy. In another recent paper, Badruzzaman⁵ also indicates that the linear nodal equations can be placed in weighted diamond form (with or without Walters' approximation). His paper contains results from 3-d calculations.

One requirement for implementing the linear nodal method in TORT was that the method must work for geometries that contain voids or near voids such as the air inside a concrete building. The equations in the appendix of Reference 5 are indeterminate as the total cross section, α ,

approaches zero. The equations used in TORT were derived much like the derivation outlined in Reference 4 and do not divide by zero when σ equals zero.

A consideration in the performance of the linear nodal method is the behavior of the linear terms in the expansion of the surface fluxes and scattering source. Consider the expansion for the flux on the left face of a mesh cell.

$$\psi_L(y,z) = \psi_L + \theta_{L,y} \frac{2(y-\bar{y})}{L_y} + \theta_{L,z} \frac{2(z-\bar{z})}{\Delta z} \quad (1)$$

If the magnitude of the coefficients of the linear terms $\theta_{L,y}$ and $\theta_{L,z}$ is sufficiently large, the expansion will be negative for certain values of y and z . Furthermore, it is also possible that negative results can be obtained for other quantities such as ψ_R , the average flux on the right face.

References 4 and 5 both indicate satisfactory results for their test problems with no fixups used to insure positive fluxes, but such is not the case for the problems of interest here. When the linear nodal method was applied to a concrete building problem, negative scalar fluxes were calculated, and attempts to converge the scattering source by inner iteration resulted in a rapidly divergent process. This divergent process occurs even in the absence of inner iteration acceleration. Thus, the linear nodal method is not applicable to concrete building problems without some corrections to insure positive or at least nondivergent results.

Apparently, the presence of near voids is the cause of the divergent behavior. The sample problems in References 4 and 5 use significant total cross sections at all points in the geometry, providing attenuation and improving stability.

Previous work by the authors⁶ developed upper and lower limits for the linear coefficients of the flux and source expansions for 2-d geometry. In that work, the magnitude of any coefficient (such as $a_{L,y}$ in Eq. 1) that falls outside the limits is reduced, insuring positive results. The 2-d work has been extended to 3-d for use in TORT. One complication in 3-d is that two terms appear in Eq. 1, while only one appears in 2-d. In 3-d, the positive fixup is based on insuring that the combined contribution of ψ_L , $a_{L,y}$, and $a_{L,z}$ to quantities such as ψ_R is positive. A less restrictive, but not guaranteed positive fixup (relaxed fixup) is to require the contribution of ψ_L and either $a_{L,z}$ or $a_{L,y}$ be positive. Both of these methods are tested in the mesh refinement study to follow.

After the negative flux fixups were installed in TORT, the linear nodal method was tested on a 3-d building previously calculated with weighted difference.¹ This building contained a thin partition in which the flux dips slightly. However, the nodal method predicted a flux increase of a factor of 2.3 in that partition, an incorrect and unsatisfactory result. To understand the cause of this problem, consider the weighted diamond form of the nodal equation for the average flux on the right face

$$\psi_R = (2 - \alpha_x) \psi_{av} + (\alpha_x - 1) \psi_L + \text{linear coefficient terms} \quad (2)$$

Here ψ_{av} is the average flux in the mesh cell. Thus an α_x of zero corresponds to the linear-diamond model and an α_x of one corresponds to the step model. Normally, weighted difference coefficients are required to be between zero and one.

However, the expression for α_x in the nodal formulation results in values between zero and two. Applying a step limit by setting values of α_x that are greater than one to one removes the incorrect flux peak.

A mesh refinement study was performed for a one group problem with geometry similar to the TORT validation experiment conducted at the Tower Shielding Facility. The coarsest mesh used had 7 intervals in the x direction and 4 intervals in the y and z directions. The finest mesh was 63 by 36 by 36. The results of this study are shown in Table 1. The problem contains 17 zones, and the error in the average flux in each zone was determined assuming the finest mesh linear nodal method with relaxed fixup is correct. For this problem, the two linear nodal methods have significantly smaller maximum flux errors than the weighted difference results. The linear nodal results with the relaxed fixup was superior to the linear nodal results with guaranteed positive fixups.

In conclusion, the linear nodal method has been extended to a new class of problems containing near voids. Needed developments included corrections to limit negative fluxes and a step limit for the weighting coefficient. These extensions to the linear nodal method are absolutely essential to large concrete building studies.

Table 1.. Maximum Flux Error for Different Meshes and Methods

Mesh	Linear Nodal Positive fix-up	Linear Nodal Relaxed fix-up	Zero Weighted	Theta Weighted
7x4x4	25.5%*	15.2%	97.3%	52.6%
14x8x8	12.4%	6.1%	65.2%	29.6%
21x12x12	8.4%	3.3%	49.0%	19.3%
28x16x16	6.0%	4.8%	39.1%	13.6%
35x20x20	4.3%	2.8%	32.4%	9.7%

* This error is 52.0% without the Step Fix-up

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