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Glass-Related Injuries in Oklahoma City Bombing[a]

Discussion by Milton M. Rudick,[6] P.E., Life Member, ASCE

The authors were very thorough in the intense study that they performed in this paper. The discusser was impressed with the amount of detail, research, and study that went into this paper. It pinpoints the need to study and design relative protection for people who happen to be in the wrong place at the wrong time. These comments are intended to offer suggestions for improvement and clarification of this paper.

It is this discusser's feeling that an abstract should be short and easy to read, in order to invite those with mild interest in the subject matter to read and study the rest of the paper. It appears to the discusser that such terms as "fenestrations vacated by fractured glazing" would be more clear and attractive to the reader if reduced to words like "broken windows" (Part of the discusser's function in his practice as a Forensic Engineer is to report a technical cause of damage in such terminology that the nontechnician can understand it.)

After a bit of confusion on the part of the discusser, it was realized that photos 3 and 4 had been transposed. After that, the explanations became understandable. In the same vein, it was realized that NW 5th Street was really a north-south dividing line, not an east-west dividing line. Also, the discusser was looking for some sort of data on eye-related injuries, but it was nowhere to be found.

Finally, the discusser congratulates the authors for this study, which he hopes will work towards additional study to find safer fenestration materials and techniques.

Closure by H. Scott Norville[7]

The only error of which I am aware in this paper is that Figs. 3 and 4 got reversed. The figure with the concentric circles should have been Fig. 4, and the map of buildings should have been Fig. 3.

[a]May 1999, Vol. 13, No. 2, by H. Scott Norville, Natalie Harvill, Edward J. Conrath, Sheryll Shariat, and Sue Mallonee (Paper 18132).

[6]Board Chair., Rudick Forensic Engrg., Inc., Youngstown, OH 44502.
[7]Dir., Glass Res. and Testing Lab., Dept. of Civ. Engrg., P.O. Box 41023, Texas Tech Univ., Lubbock, TX 79409–1023.

Damage and Distortion Criteria for Residential Slab-on-Grade Structures[a]

Discussion by Geoffrey D. Hichborn Sr.,[3] P.E., Member, ASCE, and Kenneth B. Bondy[4]

The discussers' experience with as-built residential slab-on-ground levelness differs substantially from that reported by the authors. We have observed that construction levelness for such concrete slabs is generally consistent with the American Concrete Institute (ACI) Committee 302 report *Guide for Floor and Slab Construction* (ACI 302.1R-96). This is a particularly useful document, since it not only recommends construction levelness tolerances for slabs with various occupancies, but it also relates anticipated as-built slab levelness to the finishing equipment and techniques used in their construction. It is curious that the authors did not cite this report as a reference. It is precisely on point and, along with its predecessor (ACI 302.1R-89), has been available now with substantially the same information for more than ten years.

The authors are of the opinion that slab levelness is a linear function of plan area (pp. 125–126). They feel that a "normally proportioned" residential ground-supported slab with a plan area of 2,045 square feet would "most likely" be built with a maximum difference in surface elevation of 1/2 inch. Presenting levelness criteria as a function of plan area unnecessarily obscures a direct comparison with the cited ACI recommendations, which are based upon a maximum difference in surface elevation occurring over a specified horizontal distance, rather than within the total surface area of the slab. However, the comparison is not impossible.

If the 2,045 square foot slab is square in plan shape, each side of the square is roughly 45 feet long and the diagonal distance is about 64 feet. The authors' levelness criteria is independent of the precise locations of the slab high and low points; therefore, they could presumably occur anywhere within the 2,045 square feet of slab area. If the high and low points (differing, say the authors, by a maximum of 1/2 inch) of the slab are at diagonal corners (and the slab slopes uniformly between those two corners), the minimum local levelness F-number (F_L) for the slab would be $12.5 \times 64/(0.5 \times 10) = 160$ (the ACI standard "F-number" system for slab levelness is described in the previously referenced ACI 302 document, Section 8.15; in ACI 117-90, *Standard Specifications for Tolerances for Concrete Construction and Materials*, Section 4.5.6.; and in ASTM Specification E1155). Extraordinarily flat and level floor slabs (called "superflat"), required for such applications as high-bay, narrow aisle warehouses, television studios, and ice rinks, have F_L numbers in the range of 50 to over 100, with the floor's flatness increasing with increasing F_L number. To achieve such an extraordinarily high degree of levelness, extremely sophisticated finishing techniques and equipment are required, such as hydraulically operated, laser controlled vibrating screeds. Just the cost of finishing superflat slabs often exceeds all other construction costs for the slab

[a]August 1999, Vol. 13, No. 3, by Edred T. Marsh and Scott A. Thoeny (Paper 18485).

[3]Pres., Hichborn Consulting Group, 1944 N. Tustin Ave., Orange, CA 92865. E-mail: hichbornsr@hichborn.com
[4]Consulting Struct. Engr., 6520 Platt Ave. #651, West Hills, CA 91307-3218. E-mail: kenbondy@cs.com

combined. Such equipment, to the best of the discussers' knowledge, has never been used to finish residential ground-supported slabs. It is likely that a slab with F_L = 160 (after converting the authors' description to the F_L system for a newly cast "normally proportioned slab") has never been built anywhere for any application.

If the high and low points are on opposite sides of such a slab (45 feet apart) the local F_L number would be 112.5, putting it at the upper end of the superflat range, and still requiring the use of finishing equipment, which, to our knowledge, has never been seen on any residential site. Even if the authors' maximum 1/2 inch difference in elevation occurred over just 10 feet, that would represent a local F_L = 25. The cited ACI 302 report states (Table 8.15.3.a, p. 46) that a vibrating screed with multiple strikeoffs is required to consistently achieve local F_L numbers greater than 20. Thus, at minimum, a vibrating screed would be required to achieve the degree of as-built levelness the authors consider as "most likely" to be found in typical residential slab-on-ground construction. Vibrating screeds are very rarely, if ever, used to finish residential ground-supported slabs. To the best of our knowledge, a vibrating screed has never been used to finish such a slab.

The discussers recently had the opportunity, as forensic consultants in a construction defect litigation case in California, to supervise the design, construction, and examination of four full-scale slabs-on-ground using typical California design details and construction techniques. The plan dimensions of the slabs were 12 feet by 48 feet, the slab thickness was four inches, and a down-turned grade beam was built at the perimeter and at selected locations at the interior of the slab. Finishing of the concrete was by wet-screed strikeoff (with a 2 × 4 board) and bullfloating, a finishing method used for decades on the vast majority of California residential slabs-on-ground.

One of the purposes of these "test slabs" was to determine as-built surface levelness. This was done by making a level survey of the slab surface within two days of placing the concrete and monitoring levelness periodically thereafter. Considering the fact that the placing and finishing crews were highly experienced, the placing and finishing of the concrete was continuously observed and scrutinized by a large group of bystanders (some in suits and ties!), and as the narrow dimension of the rectangular slabs measured only 12 feet, we feel that the as-built levelness of these test slabs should exceed, or greatly exceed, that found in normal residential "production" slab work.

The maximum difference in as-built surface elevation the discussers measured in these four slabs ranged between 0.5 inches and 0.9 inches, averaging 0.7 inches. The slabs exhibited an average local F_L number of 19, which, considering the unique circumstances of the test cited, is very consistent with ACI 302 recommendations. It appears that Marsh and Thoeny would predict, using their reported criteria for as-built levelness, a maximum elevation difference in any of the four slabs, each having a plan area of 576 square feet, of 0.14 inches, about one-fifth of the actual average value we measured and about one-sixth of the maximum value measured.

Results from these test slabs, coupled with the discussers' combined experience (with over 10,000 residential slab and footing designs and over 30,000 slab and footing investigations in California) differ significantly from the findings reported by Marsh and Thoeny.

It is our opinion that the authors' estimate of typical as-built construction levelness (1/2 inch maximum difference in elevation between any two points on a slab with 2,045 square feet of slab surface area) is simply not credible and grossly overestimates the actual surface levelness normally found in residential slab-on-ground construction.

Discussion by E. David Colbaugh,[5] Member, ASCE

The authors have presented the results of a relatively exhaustive study of a large database of distress inventories and corresponding manometer surveys of structure slabs-on-grade. The summary of the study is presented in tabular form, which relates level of damage to slab cracks as well as the overall differential levelness of the slab (Δ), and the angular distortion (δ/l) over 3 m (10 ft) and 6.1 m (20 ft) spans. The discusser believed there are several problematic issues involved in the presentation and interpretation of the data in this study, especially in the areas of lower levels of damage [i.e., less than 4 cm (1.6 in.) of cumulative differential]. These issues are: (1) the mechanism of the interior/exterior wall cracking; (2) the determination of the cumulative elevation differential; and (3) the interpretation of the elevation data in determining the angular distortion.

MECHANISM OF CRACKING

Several of the more common causes of wall cracks and/or frame distortion other than soil displacement in mass-produced wood-frame residential housing in Southern California are: (1) structural deficiencies; (2) construction errors and/or omissions; and (3) material shrinkage (i.e., lumber, grout, and/or cement/stucco). Wall cracks and/or frame distortion that develop as a result of any of these mechanisms are effectively indistinguishable at low levels of damage where patterns have yet to be established.

CUMULATIVE DIFFERENTIAL

With the exception of the very limited study by the authors (6 homes) and that given by Koenig (1991) (54 homes), the issue of how level the slabs-on-grade were initially constructed has been avoided. Based on the discusser's experience, the levelness of the slabs-on-grade of the homes studied by the authors (i.e., range of relative elevation difference from 1.5 to 2.5 cm (0.6–1.0 in.) appears to be in the average range for small to moderate size homes [i.e., up to 350 m^2 (3,500 ft^2)] and more the exception rather than the norm, for larger structures [i.e., 790 m^2 (8,500 ft^2)]. The comparison of the data from the authors' studies to Koenig's relationships is out of context in that there is no basis for proportioning levelness on slabs-on-grade to surface area. Additionally, the authors have only quoted Koenig's conclusion, which is misleading, because Koenig derived that conclusion by analyzing only that data obtained from around the perimeter of the structures and ignored data taken within the interior of the slabs-on-grade:

> "Since there was such a noticeable trend of the edges being lower than the center zero, and since elevation comparisons are generally made along foundation edges, the statistical study proceeded by analyzing the differences in the data from the exterior locations only."

Intuitively, since the perimeter of the structure is the closest to the form work, one would expect these measurements to exhibit the smallest relative elevation differential. Thus, the issue of overall differential remains unresolved if the anomalies in the surface of the slabs-on-grade as constructed are ignored.

[5]Prin. Engr., Evans, Colbaugh, and Assoc., Inc., 2453 Impala Dr., Carlsbad, CA 92008.