PERFORMANCE OF MANUFACTURED HOMES DURING HURRICANE EMILY

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Introduction

On August 31, 1993, Hurricane Emily struck southern Dare County, North Carolina. Preliminary reports from the affected areas indicated that approximately 520 homes (over 160 manufactured homes) were damaged or destroyed. The greatest damage occurred in the vicinity of the unincorporated communities of Avon and Buxton on the Outer Banks. High winds and flooding in those areas originated primarily from Pamlico Sound and resulted in stillwater elevations from 8 to 11 feet above normal sea level. The Cape Hatteras Weather Station anemometer was reported to have "given out" during the storm at a recorded wind speed of 100 mph. The highest wind speed recorded at Avon during the hurricane, 107 mph, is considered to have been the peak gust during the storm.

Immediately after Emily struck, the Federal Emergency Management Agency (FEMA) authorized Greenhorne & O'Mara, Inc., to visit the Outer Banks to conduct a preliminary field assessment (PFA) in the Buxton and Avon areas (including the unincorporated areas of Frisco). The PFA process is one of two major phases of post-disaster building performance assessments that FEMA typically conducts. The other, which is more comprehensive, is the building performance assessment team (BPAT) process. The PFA is typically limited in scope and direction and is intended to be a preliminary evaluation/assessment of the types and severity of damage caused by a given disaster. As a result of the PFA, a BPAT may be recommended and authorized by FEMA in order to conduct a more comprehensive assessment of the structures damaged by the disaster and to identify future mitigation measures.

Some of the major goals established for the PFA visit in the Outer Banks included documenting the nature and magnitude of the damage to manufactured homes (MHs), identifying successful and unsuccessful performance of foundation systems, identifying any units not in compliance with the National Flood Insurance Program (NFIP), estimating the number of MH units affected, assessing the severity and depth of flooding as compared to the 100-year flood elevations depicted on the Flood Insurance Rate Map for the unincorporated areas of Dare County, and identifying unique site and soil conditions pertaining to structural fill, scour, etc.

Preliminary Field Assessment

The PFA was conducted September 13-15, 1993. Of the 60 MH units visited, 46 were located in two MH parks (Tex Ballance Trailer Park in Buxton and Ocean Village Resort Trailer Park in Avon). Single-wide MH units and their foundation systems consisting of pier members, tension straps, and ground anchors were visually inspected. The scope of the field evaluation was limited to identifying performance characteristics (resistance to lateral movement, flotation, and/or collapse) of the MH foundation systems in response to wind, hydrodynamic, and hydrostatic forces generated by the storm. NFIP floodplain management regulations require that MHs be elevated on adequately anchored foundation systems and be able to resist flotation, collapse, and lateral movement during occurrence of the base flood.

"Failure" of a MH unit foundation system, as defined in the PFA, refers to the inability of a foundation system to resist the lateral (wind and water) forces, impacts from incidental debris, and net uplift (buoyancy and wind) experienced during Hurricane Emily. MH units that were not damaged or were flooded above their flooring yet whose foundation systems successfully resisted horizontal and uplift forces were deemed "successful" in meeting the NFIP requirements for resisting lateral movement, flotation, or collapse, even though some of those units' flooring, walls, and contents suffered water damage.

The foundation systems of all of the MH units visited consisted of a steel chassis system (with two I-beams) atop a system of dry-stacked block piers on concrete or block footing pads, tied down with galvanized straps that connected to augured ground anchors. All of these elements were intended to operate in tandem to stabilize an elevated MH unit in its weaker transverse direction against movement, overturning, and flotation (Figure 1). It is important to note that all of these force-resisting links (the chassis, strapping, and ground anchors) need to work together to achieve an overall load transfer path and that the entire foundation system is failure-prone if any of these members is missing, inadequately installed, or poorly maintained.

The factory-made chassis I-beam and floor structure of the MH unit itself is typically fairly rigid in the direction of flood forces. However, the chassis connection to the dry-stacked piers is an on-site fabrication with potentially unstable characteristics.

The gravity and tension-force-resisting chassis-to-pier connection typically began with a simple seat: the chassis I-beam sat on a combination of shims and a wood plate, which rested on top of the pier. The wood plate and

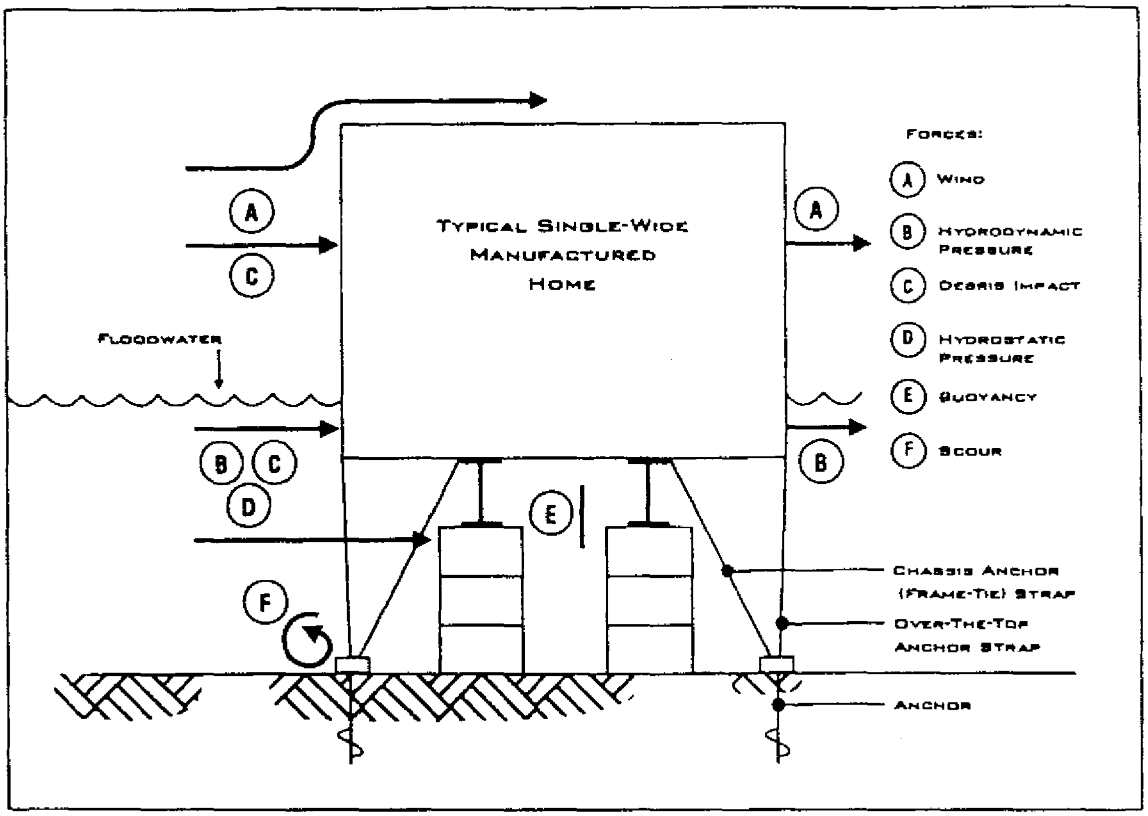

Figure 1. Typical forces acting on a manufactured home in a floodplain.

shims were typically not "fastened" to each other or to either the chassis or pier. They were held in position by the weight of the MH unit and the additional force of friction caused by tensioning of the galvanized straps. In effect, the strapping provided a clamping force for all the parts: the piers, the plates, the shims, and the MH.

In general, when the strapping is loosened (for whatever reason) the entire system becomes unstable. In many cases, the MH is acted upon by lateral forces (e.g., floodwater acting above the first floor line in combination with wind) that exceed the horizontal frictional forces from the weight of the MH alone, and therefore movement of the MH occurs. Also, the piers tilt in the direction of the lateral forces. This tilting may then cause rotation at the top of each pier away from the base of the chassis because the chassis remains rigidly fixed to, and at right angles to, the floor of the MH. The effect of the resulting loss of any contact friction between the chassis and the plates/shims greatly reduces the lateral force resistance of the foundation system. Since buoyancy and/or wind uplift forces may be present, they compound the problem by causing the entire separation of the contact surfaces.

As the rotation and tilting of the dry-stacked piers increases, the foundation system below the chassis I-beam becomes unstable. Unlike concrete-grouted steel-reinforced piers, dry-stacked piers do not possess sufficient "elastic" properties to permit them to return to their preflood alignment once forces acting on them have abated. Consequently, once stormwaters recede and winds diminish, a previously buoyant MH would rest on out-of-plumb vertical supports. And if there is sufficient water current to push the MH farther downstream of the piers, total failure may result.

It was apparent from the observations of the "failed" foundations of MH units after Hurricane Emily that one particular sequence of failure was prevalent. The typical failure began with a shifting of the tops of the piers in the transverse direction most directly in line with the winds and flood current that came from Pamlico Sound in a northwesterly direction. This action caused a rotation of the individual piers and a separation of the connection between the steel chassis members and the tops of the piers, as noted earlier. The resulting movement of the foundation systems as observed was that of piers now out of plumb and, in extreme cases, racked to a point of total collapse. It was apparent that when floodwaters rose above the first floors of many MH units, the structures became buoyant, and as floodwaters receded, the MH units came down to rest off-center on an unstable foundation.

In a second, less-frequently observed, failure mode, where the system suffered significant strap and anchor failure (total anchor withdrawal from the soil and/or broken straps), the MH unit floated or pivoted significantly from its original position and came to rest at trees or other barricades. This failure mode was observed for a few units where total withdrawal of anchors and strap failure occurred. Because of the pure tension failure of the strap and the withdrawal of all anchors, it is suspected that these units (assumed to have been installed properly) may have been subjected to excessive wave forces occurring at or near the units' floor levels. Although wind was an obvious contributor to the foundation system failures, the MH skin (which is designed for 25-psf unit wind loading) did not show the type of damage that would suggest either that wind acted alone or that waves hit the MH significantly higher than the floor level. However, where foundation system failures were prevalent, slack in the straps and inadequate embedment of anchors were observed.

Observations of the results of various degrees of horizontal movement and collapse due to the typical failure modes were made in both the Tex Ballance and Ocean Village trailer parks. Several units had straps that became loosened and anchors that partially or fully withdrew under the stresses of the storm caused by racked or partially racked piers. While many foundation systems failed through the typical modes described above, others of exactly the same design (with or without mortar) experienced identical forces yet performed quite well.

Conclusions

Based on the field evaluation, scour and erosion did not contribute to the observed failures. Rather, it appeared that inadequate installation of the MH foundation systems (e.g., inadequate anchor embedment depth, inappropriate type of anchor used, inadequate connection of straps to I-beam) or lack of maintenance of the tiedown system, or both, significantly contributed to the majority of foundation system failures in the area. Moreover, the fact that many anchors performed well and that many of these were located next to failed anchors brings into question the adequacy of the installation of some of these anchors. One of the Dare County building officials indicated that the county was concerned that some screw augers may have been installed to their *full* 4-foot embedment with post-hole diggers. This method is contrary to the manufacturer's recommendations, which allow excavation by post-hole diggers to a maximum of 2 feet and specify that the auger then be turned in by hand the remaining 2 feet and the soil repacked. The basis for the recommended installation method is that auguring in undisturbed soil provides greater pullout resistance than backfilling excavated soil around the auger discs.

When dry-stacked piers were installed correctly to elevate the MH to the base flood elevation (BFE), the piers, in combination with post-tensioned straps and properly installed ground anchors, proved capable of withstanding the wind and flood forces of Emily. This conclusion is reinforced by the successful performance of systems that had the same 36-inch pier height and foundation configuration and that also experienced water and wave damage in excess of their floor lines.

Post-Hurricane Reconstruction

As of April 1, 1994, approximately 71 new MH units had been installed in Dare County to replace those damaged or destroyed by Hurricane Emily. Roughly 10 additional MH units have been replaced by site-built homes. New MH units are being elevated up to two feet above BFE predominantly upon a state-sponsored post-tensioned dry-stacked block pier system with reinforced footings extending below grade designed by a registered professional engineer. Although FEMA has determined that the concept of this design would enable the home to meet the performance standards set forth at CFR 60.3(c)(6), its ultimate success is dependent upon maintaining adequate strap tension and anchor pullout strength. Dare County building officials are tracking the locations of units elevated using this foundation design to enable them to evaluate their performance during future extreme wind and water events. Local and state officials will monitor homeowner maintenance of straps and anchoring systems, including strap tension, anchor installation, and corrosion.

At the request of the state, a pile foundation was designed by FEMA and Greenhorne & O'Mara for use in replacing MHs damaged after Emily and throughout North Carolina. Due to the higher costs and more complex setup procedures for this type of foundation, it has not been used to date in the Outer Banks to replace the damaged MHs.

New Wind Requirements for MHs

Since Hurricane Emily brushed the Outer Banks, the Department of Housing and Urban Development (HUD) published a final rule requiring that the structural components, cladding, and anchoring/foundation systems of manufactured homes destined for hurricane-prone areas be designed in accordance with the design wind pressures and wind speeds specified in the American Society of Civil Engineers standard ASCE 7-88. By July 1994, manufacturers of MH units and of stabilizing equipment (straps and anchors) must redesign elements of the building and foundation system components to meet standards similar to those required for site-built and modular homes. In discussions with FEMA, HUD officials indicated that this higher construction standard may eventually result in the use of more permanent foundations in coastal high wind areas, i.e., no dry-stacked block, and less reliance on straps and anchors to withstand overturning and collapse. Eventually, ground anchors may become obsolete in coastal areas simply because they will not be able to resist increased wind load requirements.

FEMA believes that these higher standards will result in stronger foundation and stabilizing system components, and increased attention to installation practices in the coastal areas affected by the rule. When MH units are properly elevated to or above BFE, this stronger foundation will provide greater resistance to the wind and flood forces produced during hurricanes. Manufactured homes are an important component of the housing stock in the Outer Banks because of the population's income levels and because they are used as second homes. Although the magnitude of damage to these MHs in Emily did not approach that experienced during Hurricane Andrew (which prompted the development of the new HUD rule), these new standards will better enable manufactured housing to resist the extreme forces produced by the coastal storms that are so much a part of life on North Carolina's Outer Banks.

DEVELOPING TECHNICAL GUIDANCE MATERIALS ON ELEVATING SUBSTANTIALLY DAMAGED BUILDINGS IN THE MIDWEST UNITED STATES IN RESPONSE TO THE GREAT MIDWEST FLOOD OF '93

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Introduction

In August 1993, as the floodwaters of the Mississippi River were receding from their peak flood stage, the Federal Emergency Management Agency (FEMA) assembled an interdisciplinary field team of building scientists, architects, engineers, and professionals versed in flood hazard mitigation. The team assessed the performance of buildings (mostly housing) that were subjected to flooding and groundwater increases and prepared guidance on how to elevate residential buildings to reduce future flood losses (FEMA, 1993). The area of special interest was the State of Illinois from Galena south to Hull, within the Mississippi River floodplain. This area included urban, suburban, and rural settings, with a mix of manufactured, stick-built wood-frame, and masonry housing. The vast majority of the housing was wood-frame construction on a variety of foundation types. This paper describes the flood-induced damage to homes, the development of the technical guidance to mitigate this damage through elevation, and how the engineering and cost guidelines were developed through the use of local architectural and engineering expertise to assist localities in meeting the elevation requirement contained in the substantial damage provisions of the National Flood Insurance Program (NFIP) regulations.

The NFIP regulations, 44 CFR 59.1, define substantial damage as ". . . damage of any origin sustained by a structure whereby the cost of restoring the structure to its before damaged condition would equal or exceed 50 percent of the market value of the structure before the damage occurred." Section 60.3(c)(2) of the regulations states that if a substantially damaged building located in a designated Special Flood Hazard Area is to be rebuilt, it must be elevated so that the lowest floor is at or above the base flood elevation (BFE). The BFE is the elevation reached by floodwater during a 100-year flood (i.e., the flood that has a 1% probability of being equaled or exceeded in any year). The requirement to elevate substantially damaged buildings must be met regardless of the cause of the damage to the structure. Since little new development has occurred in many of the communities along the Mississippi River in Illinois, many local governments were unfamiliar with this NFIP requirement, even though it is contained in the floodplain management ordinance enacted by each community participating in the NFIP.

Development of Technical Guidance

The field team assembled on Sunday, August 8, 1993, in Moline, Illinois, to tour the flood-affected areas from Moline south to Hull. After surveying the damaged areas, the team developed a typical profile of the building types and methods of construction. Most of the observed damage was a result of inundation of the homes for, in some instances, over a month. This long-term inundation led to the complete saturation of the homes. In northern Illinois, and throughout the state along the Mississippi River and its tributaries, the depth of the standing water generally ranged from 1 to 8 feet. In southern Illinois, the depths ranged from 8 to 16 feet. It was also interesting to note the large number of basement wall and foundation failures that occurred in homes that were not flooded by surface waters but were located in areas with saturated soils outside the floodplain. The typical residence was a one- or two-story (1,000-square-foot) wood-frame structure on a masonry (brick, block, fieldstone) basement or crawl-space foundation or on a slab on grade. After inspecting the types of construction and the damage incurred, FEMA, Greenhorne & O'Mara, Inc. (G&O), and G&O's consultant, Shive-Hattery Engineers and Architects, Inc., promptly assembled additional professionals to prepare and present the technical information on elevating residential structures. This design team consisted of a residential architect, a structural engineer, a civil engineer (an active residential home builder), a floodplain management expert, and a geotechnical engineer. Working together, the team members provided guidance on the feasibility and applicability of the various elevation techniques considered for a typical residential structure in the Midwest. Guidance was also provided on compliance with NFIP, state, and local floodplain regulations and requirements. Computer-generated illustrations of the elevation techniques were produced.

The design team developed seven alternative elevation techniques that were technically feasible and cost-effective for this region of the Midwest.

A Elevating a wood-frame home over a crawl-space structure,

B Creating a new masonry enclosed area on top of an abandoned basement,

C Elevating a slab-on-grade wood-frame structure without the slab (proposed first floor: wood truss),

D Elevating a slab-on-grade wood-frame structure without the slab (proposed first floor: concrete slab),

E Elevating a slab-on-grade wood-frame structure with the slab intact,

F Elevating a wood-frame-over-crawl-space structure on masonry piers, and

G Elevating a wood-frame-over-basement structure on masonry piers.

Figure 1 illustrates the type of information (drawings and wall section details) provided to local governments and homeowners for each of the proposed techniques. The technique shown in Figure 1 allows for the elevation of the typical substantially damaged one- or two-story structure on an existing crawl space by adding to the existing foundation walls, resulting in a structure with a lowest floor or at above the BFE. With the installation of foundation wall openings and the elevation of utilities and mechanical equipment above the BFE, the structure complies with the NFIP requirements. All the proposed techniques comply with state and local building codes as well as NFIP requirements. It should be noted that during the team's tour of site conditions in Illinois, several of these techniques were seen to have been used by homeowners in the past. Most of the homes that were previously elevated in this fashion survived the 1993 flood with little or no damage.

To address seismic concerns in the southern portion of the state, additional guidance was included in the technical information package. This information was developed in accordance with the National Earthquake Hazard Reduction Program (NEHRP) minimum recommended provisions and consisted of literature, technical drawings, and estimates of the associated costs of seismic retrofitting procedures that could be employed when elevating homes in accordance with NFIP requirements.

The design team then developed detailed cost estimates for the alternative techniques considered using standard construction costing methods (Table 1). The team's local engineering staff was highly experienced in residential development in the Midwest and intimately familiar with the technical challenges associated with the alternative elevation techniques considered. This translated into accurate localized cost estimates for each technique. After the cost estimates were prepared, the pricing structure for each method was con-

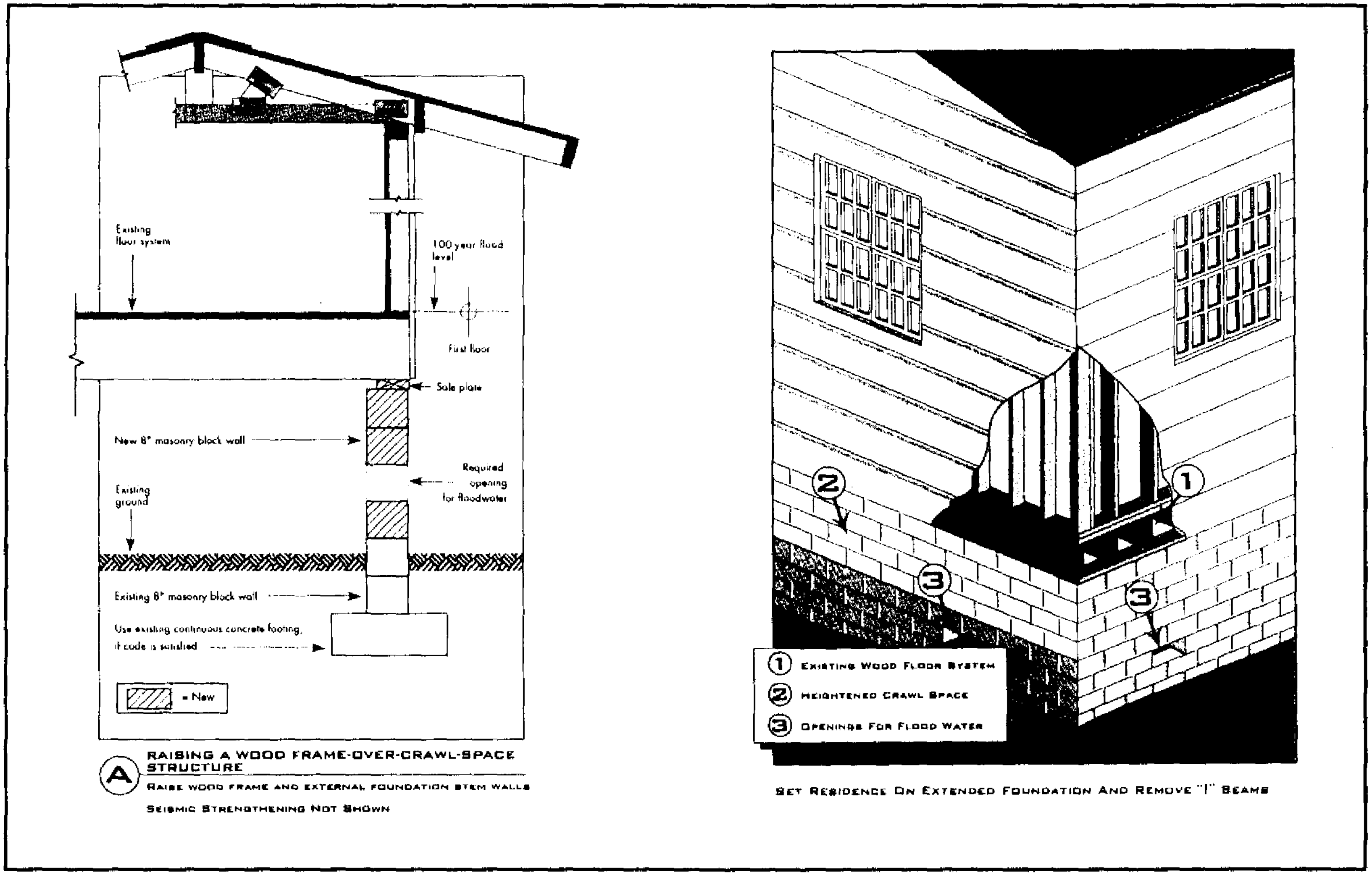

Figure 1. *Examples of technical guidance materials.*

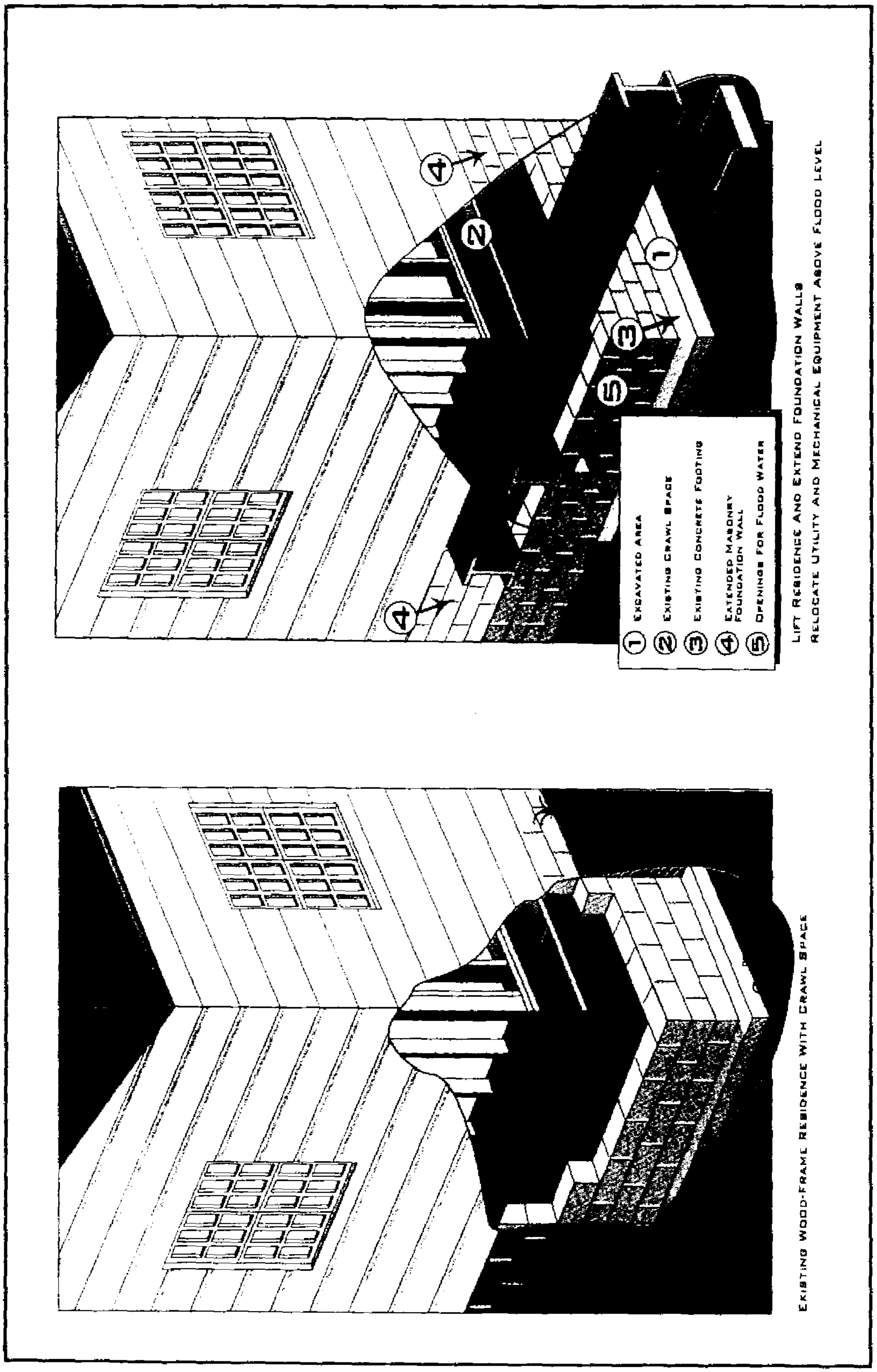

Figure 1. (cont.)

verted into a simplified per-square-foot cost that homeowners could easily use to calculate the cost of elevating their homes. All the cost estimating procedures presented by the team were "user-friendly" and were provided with clear directions for homeowners' use.

Table 1. Cost spreadsheet for alternatives.

COST COMPARISONS[1] FOR ELEVATING SUBSTANTIALLY DAMAGED RESIDENTIAL BUILDINGS IN THE MIDWEST (1,000-SQUARE-FOOT WOOD-FRAME STRUCTURE)

HEIGHT ABOVE GRADE HOME IS BEING ELEVATED	ALTERNATIVES							
	A[2]	B[2]	C[2]	D	E[2]	F	G	H[3] (DEMOLITION)
1 TO 3 FEET	$20,000	$26,500	$23,500	$24,600	$32,100	$23,900	$28,500	$5,500
4 FEET	$21,400	$27,900	$24,900	$27,100	$33,100	$24,300	$28,900	
5 FEET	$22,800	$29,300	$26,300	$29,400	$34,100	$24,700	$29,000	
6 FEET	$24,200	$30,700	$27,700	$31,700	$35,100	$25,100	$29,400	
7 FEET	$25,600	$32,100	$29,100	$35,500	$36,100	$25,500	$29,900	
8 FEET	$27,100	$33,600	$30,600	$36,400	$37,100	$26,000	$31,300	
10 FEET						$28,200	$33,500	
12 FEET						$29,500	$33,800	
14 FEET						$34,200	$35,500	
16 FEET						$35,500	$38,800	

NOTES:

1 ESTIMATED COSTS ARE PROVIDED FOR GENERAL STRUCTURAL COST GUIDANCE ONLY AND DO NOT INCLUDE POTENTIAL ADDITIONAL COSTS FOR COMPLIANCE WITH WIND LOAD REQUIREMENTS, FOR NEW ROOFING SYSTEM, FOR SEISMIC STRENGTHENING, OR FOR GENERAL CONTRACTOR CHARGES, OR ANCILLARY COSTS SUCH AS ELECTRICAL, PLUMBING, FINISHING, AND OTHER NON-STRUCTURAL COSTS.

2 NO FINISH IN NEW MASONRY ENCLOSED AREA.

3 DEMOLITION DOES NOT INCLUDE ENVIRONMENTAL ASSESSMENT AND/OR CLEANUP COST

The information developed by the team was disseminated to Illinois state and local governmental staff, local architects and engineers, and interested homeowners through a series of meetings with local officials, consumer workshops, and one-on-one technical counseling with affected property owners. A publication containing illustrations of each technique was reproduced and made available by FEMA to local governments, homeowners, contractors, architects, and engineers (FEMA, 1993).

Conclusion

As the reconstruction in the Midwest continues, many of the elevation techniques recommended by the team are being used to rebuild substantially damaged homes. The cost guidance materials for elevating substantially damaged structures were well received by local officials and homeowners. The following conclusions can be drawn from FEMA's experience with substantially damaged homes in the Midwest:

- Elevation of substantially damaged structures of the type found in the Midwest is technically feasible.
- Expertise exists at the local and national levels in the design of elevated residential structures.
- Technical information can be readily transferred on a one-to-one basis with homeowners and other interested parties.
- Homes elevated before the flood of 1993 show the effectiveness of the methods proposed by FEMA.
- Pairing with local engineering and construction professionals to develop post-flood technical information provides FEMA with more realistic designs and costs of mitigation techniques for any given region and provides local officials and residents the assurance that local construction practices and costs are accurately represented.

References

Federal Emergency Management Agency
1993 *Technical Information on Elevating Substantially Damaged Buildings in the Midwest.*