**4 A.2** **Damage Survey of the Picher, OK Tornado: 10 May 2008**

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## 1. Introduction

On 10 May 2008, a large tornado struck Picher, Oklahoma, a small town in the northeast part of the state (Fig. 1). Within days after the event, the author conducted ground and aerial damage surveys of the town. Detailed house-by-house damage assessments were performed and degrees of damage (DOD) were correlated with vehicle damage. Similar damage surveys have been completed by Marshall et al. (2008a, b, and c) after other tornadoes.

The Picher tornado destroyed a large number of manufactured homes. Two failure modes were discovered in the anchoring systems: 1) removal of the anchor heads, and 2) failure of the galvanized steel straps securing the steel undercarriages. This paper will present the results of the damage survey.

## 2. Weather Situation

This was a classic severe weather day for northeast Oklahoma. Morning satellite imagery showed persistent high clouds over the region but an approaching dry slot would bring clear skies later in the day. A dryline was expected to move rapidly eastward enhancing low-level lift. Most unstable convective available potential energies (MUCAPEs) of 2000 j/kg were forecasted by the North American Model (NAM) over northeast Oklahoma by 0000 UTC.

At 1200 UTC on 10 May 2008, there was a trough of low heights at 500 mb that extended from central Wyoming, through Colorado, and into central New Mexico (Fig. 2). The nose of a 70 kt jet extended through the Texas panhandle. In advance of the trough, temperatures at 500 mb were -15C at Dodge City and Amarillo. With southeasterly surface winds and increasing southwest winds aloft, there was plenty of deep layer (directional and speed) shear in the warm sector for storm rotation.

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**Figure 1.** Large tornado moving through Picher, Oklahoma. Photograph courtesy of Donna Young.

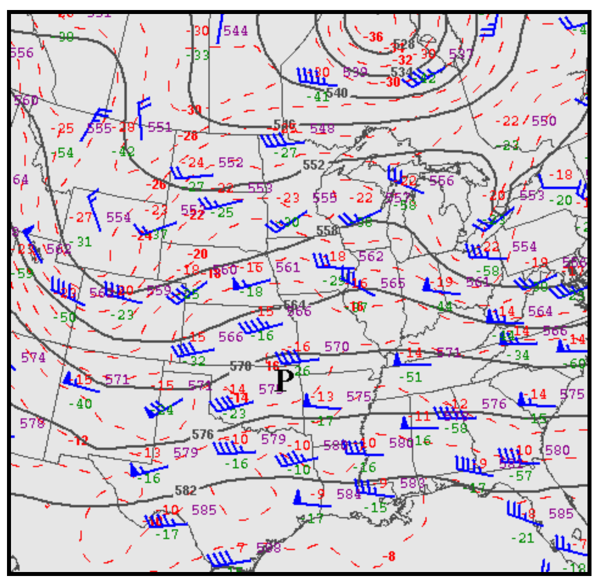


**Figure 2.** 500mb height map at 1200 UTC on 10 May 2008 showing the approach of an upper trough. The letter "P" is over the town of Picher, Oklahoma.

By 1500 UTC, a dryline extended south from a low pressure center in southern Kansas through central Oklahoma while a warm front extended east across southern Kansas (Fig. 3). Southeast surface winds in the warm sector transported moisture toward northern Oklahoma. That morning, the Storms Prediction Center (SPC) issued a slight risk of severe storms for eastern Oklahoma and southeast Kansas with a moderate risk for Arkansas east to central Georgia. Convection initiation began early in the day along a leading short wave in northeast Oklahoma and SPC issued a Tornado Watch at 1630 UTC. Storms moved quickly into southern Missouri, temporarily stabilizing the lower atmosphere. According to NOAA (2009), many people incorrectly assumed that severe weather had ended for the day and were surprised when severe weather redeveloped later that afternoon.

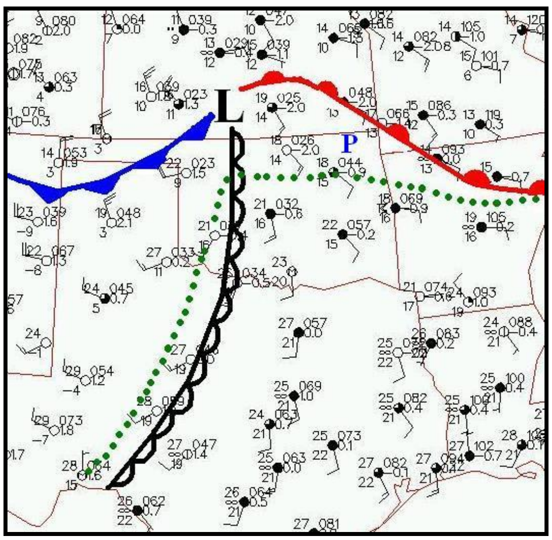


**Figure 3.** Surface weather observations for Oklahoma and surrounding states at 1500 UTC on 10 May 2008 with pertinent weather features noted. The letter “P” is over the town of Picher, Oklahoma. The 15C (59F) isodrosotherm is highlighted by the line of green dots.

The tornado that struck Picher, Oklahoma initially developed at 2220 UTC about 15 km northwest of Welsh in Craig County, near the Kansas border. The tornado moved east-southeast at a forward speed of approximately 20 $ms^{-1}$ and traveled through western and southern portions of Picher around 2240 UTC. According to NOAA (2009), the tornado killed six people and injured about 150. Maximum damage intensity was rated as EF-4 on the Enhanced Fujita Scale (WSEC, 2006). The tornado continued southeastward passing just north of the town of Quapaw, and then narrowed as it crossed Interstate 44, after traveling 42 km (Fig. 4).

Meanwhile, a second tornado developed north of Interstate 44 and moved southeast, also crossing the highway. According to NOAA (2009), the circulation of the first tornado merged with the second tornado. The second tornado traveled 11 km through rural areas of Oklahoma before crossing into Missouri around 2054 UTC and continued another 76 km before dissipating southeast of the town of McDowell in Barry County around 2155 UTC. At times, the tornado was 600m wide. The second tornado killed 15 people, many in automobiles, and damaged or destroyed rural homes. Maximum damage intensity was rated as EF-4 on the Enhanced Fujita Scale.

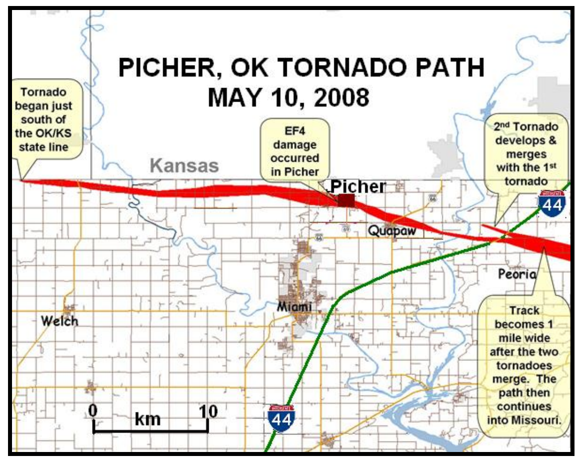


**Figure 4.** Track of the tornado that struck Picher, Oklahoma (red line). Courtesy of NOAA (2009).

### 3. Aerial Damage Survey

An aerial damage survey was conducted from a helicopter. Each block in Picher was photographed from multiple directions at an elevation of about 200 m (Fig. 5). The town was divided into three sections by topography (Fig. 6). The west side of Picher contained mostly manufactured homes and was located in a wooded area between two chat piles. The chat piles were mounds of loose tailings left over from mining operations. The center of town was along and to the east of the main north-south road, Highway 69. Houses were mostly wood-framed structures built on pier and beam foundations. A small number of wood-framed homes, including public housing, had been constructed on concrete slabs. The southeast portion of town, south and east of Lytle Creek, had both a mixture of wood-framed and manufactured homes. The aerial survey was essential to obtain a quick overview of the tornado damage path and pinpoint areas on the ground for more detailed analysis. The tornado path was consistently 600 m wide through town.

**Figure 5.** Aerial view of the tornado damage path looking south, just east of Highway 69. Pertinent features are noted. Chat piles are to the right.

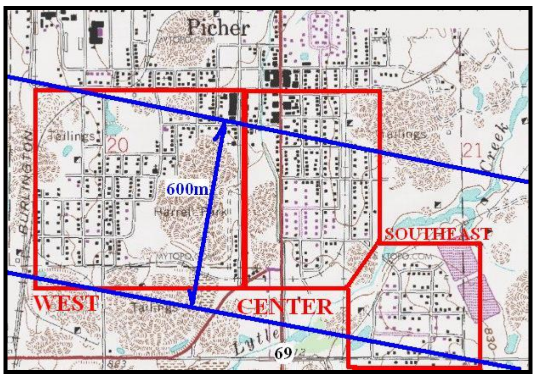


**Figure 6.** Topographic map of Picher, Oklahoma divided into three sections (red boxes). Blue lines indicate the 600 m wide damage path. Brown shaded areas are chat piles.

The most severe damage occurred in the west portion of town where the tornado rolled or lofted dozens of manufactured homes. Steel undercarriages were mangled and deposited in trees along with large quantities of other debris. The original locations of the manufactured homes were noted by long, rectangular-shaped areas of dirt that contained equally spaced piers constructed with concrete masonry units (CMUs). The piers had supported the steel undercarriages. A few manufactured homes were built on foundation walls constructed with CMUs.

Many trees were uprooted or snapped. There was a distinct convergence pattern in the tree falls with the centerline being on the right (south) side of the damage path. However, trees that remained standing became gathering points for flying debris. Some trees were debarked from debris impact.

The tornado passed south of the central business district in Picher through residential areas. A total of 166 homes and 66 manufactured homes were identified within the damage path. There also were 92 automobiles within the damage path.

An interesting note about this survey was that the tornado went through the Tar Creek Superfund site designated by the Environmental Protection Agency (EPA, 2005). The town of Picher was an active lead and zinc mining facility until the late 1960s and numerous chat piles (the waste product) were located around town. The chat piles, some greater than 50 m tall, reportedly contain trace amounts of heavy metals. Soil particles are fine and unconsolidated. The tornado went over several chat piles, likely distributing additional contaminated soil over the town. However, the presence of the chat piles had no effect on tornado intensity.

## 4. Ground Damage Survey

The author conducted a ground damage survey for both Oklahoma and Missouri tornadoes. The combined tornado paths were 129 km long. However, the results in this paper are limited to the town of Picher which comprises a total path length of just 2 km.

Cleanup of the damage began almost immediately after the tornado. Some buildings were being bulldozed during the survey. Other buildings were demolished or moved prior to the tornado (perhaps as a result of the Superfund relocation program) as grass was present within the crawl spaces of empty foundations.

### 4.1 Performance of wood-framed housing.

EF-scale numbers were assigned to 166 houses based on increasing severity of the damage (Figs. 7 and 8). Degrees of damage (DOD) descriptions were followed in accordance with those developed by the Wind Science and Engineering Center (2006).


**Figure 7.** EF-scale numbers assigned to homes in Picher based on the increasing severity of the damage.

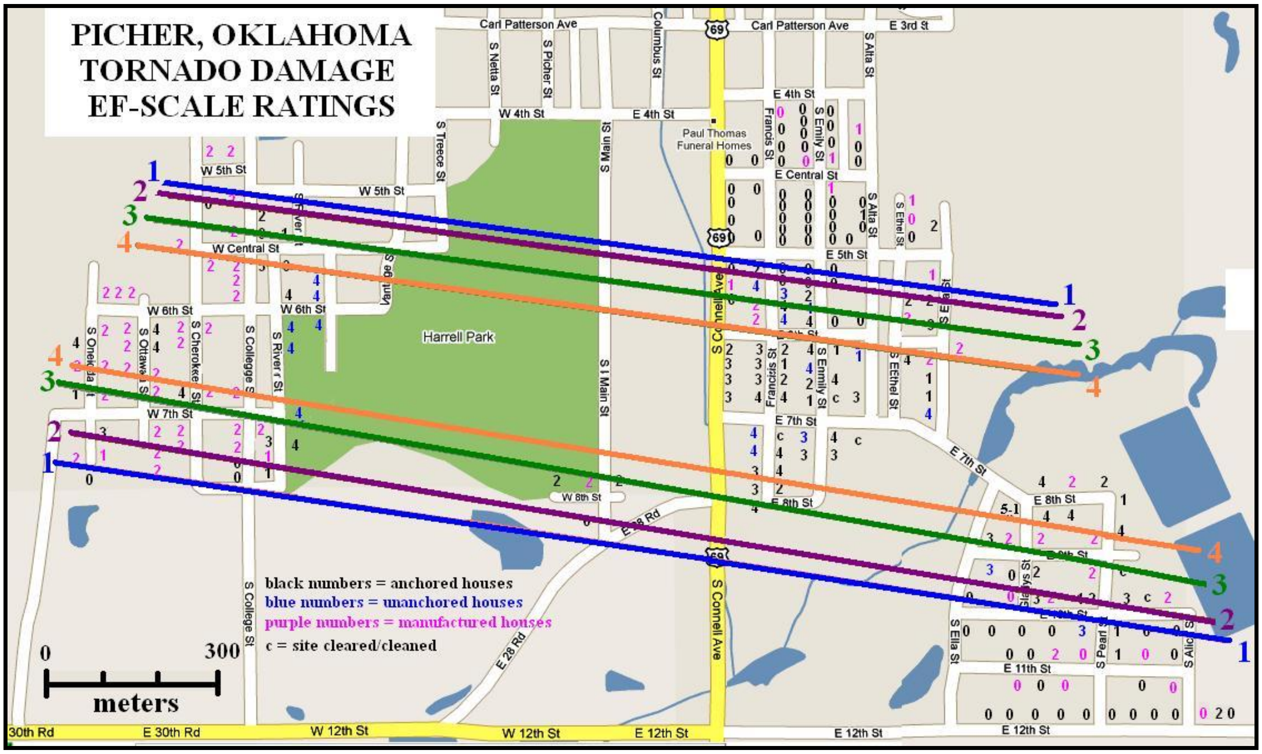


**Figure 8.** House by house EF-scale damage ratings in the Picher, Oklahoma tornado.

Damage was rated EF-0 if homes lost less than 20 percent of their roof coverings or lost siding (DOD=2). A rating of EF-1 was assigned to homes that lost most of their roof coverings or had minor structural damage to the roof such as missing gable ends (DOD=4). Damage was rated EF-2 if homes lost most of their roof structure but the walls remained standing (DOD=6). A rating of EF-3 was assigned to homes that lost most of their walls (DOD=8). An EF-4 rating was given to those homes that had all walls down with only a pile of debris remaining on their foundations (DOD=9). Table 1 summarizes the numbers of damaged homes by EF-scale. Many homes either had little to no damage or were destroyed completely. This difference was due, in part, to the sharp gradation of damage along edges of the tornado path.

**TABLE 1**
**EF-SCALE RATINGS TO HOUSES IN THE PICHER TORNADO**

| EF rating | Wind in $ms^{-1}$ | Houses | Percent |
|---|---|---|---|
| EF0 | 28-38 | 78 | 47 |
| EF1 | 39-49 | 14 | 8 |
| EF2 | 50-60 | 18 | 11 |
| EF3 | 61-74 | 22 | 13 |
| EF4 | 75-89 | 34 | 21 |
| **TOTAL** | | **166** | **100** |

Most homes in the damage path had pier and beam foundations. Wood floors were supported by CMUs. In some instances, the masonry piers had mortared joints while in other instances, the masonry was loosely stacked. Regardless, the floor platforms were not anchored to the ground.

Of the 166 homes in the damage path, 18 were identified as "sliders" where floor platforms moved off their piers. Such homes were assigned DOD numbers based on the levels of damage above floor level. Where such homes had been swept clean from their foundations, they were assigned DOD numbers based on neighboring structures that remained (Fig. 9).

A common failure was separation of the perimeter walls and the floors (Fig. 10). Wall bottom plates fell over where they had been straight-nailed to the floors or wall studs were pulled out of the bottom plates. Wall bottom plates were straight nailed to the floors with nails usually missing the floor joists. Such walls had limited resistance to lateral wind loads once the roofs were removed.

Termite and rot damage was found in many wood-framed houses. In some instances, the damage compromised critical connections between wood floors and wall plates (Fig. 11). As a result, there were a number of homes where the bases of walls were not attached to the floors.

**Figure 9.** An unanchored home that slid off its pier and beam foundation.

**Figure 10.** Bottom plate of the wall (left) failed where it was nailed to the floor perimeter (right). The inset image shows a nail that extended from the bottom plate.

**Figure 11.** Rot and termite damage to perimeter flooring beneath where the wall bottom plate had been located.

There were two homes swept clean off their concrete slab foundations. Both homes had bottom plates nailed improperly to the slabs. In addition, an elevated wood porch at one house remained intact along with railings and wood benches. At the other home, vehicles were moved but remained upright (Fig. 12). Thus, the author determined the maximum damage rating should be EF-4, rather than EF-5.

**Figure 12.** A poorly anchored home swept clean off its concrete slab foundation. The inset image shows nails along foundation perimeter (NOAA).

4.2 Performance of manufactured housing

EF-scale numbers were assigned to 66 manufactured homes based on increasing severity of damage. The damage was rated EF-0 if homes lost their roof covering or siding (DOD=2). A rating of EF-1 was assigned to those homes that lost most of their roofs and walls leaving the floor platform (DOD=6). The damage was rated EF-2 if homes were completely destroyed with debris blown away (DOD=9). Table 2 summarizes the numbers of damaged manufactured homes by EF-scale. Most of the manufactured homes (73 percent) were destroyed. Steel undercarriages were rolled or lofted while the wood framing and contents were blown downwind. A windrow of fine debris was deposited along the centerline of the tornado damage path which included small wood splinters, glass shards, and pieces of carpet padding.

**TABLE 2**
**EF-SCALE RATINGS TO MANUFACTURED HOUSING IN THE PICHER TORNADO**

| EF rating | Wind in $ms^{-1}$ | Houses | Percent |
|---|---|---|---|
| EF0 | 28-38 | 10 | 15 |
| EF1 | 39-49 | 8 | 12 |
| EF2 | 50-60 | 48 | 73 |
| **TOTAL** | | **66** | **100** |

About two-thirds of the 66 manufactured homes had been anchored to the ground. Most homes were secured with rock anchors whereas a few had auger type anchors (Fig. 13). Rock anchors were comprised of a steel head with slotted bolts. The slotted bolts were used to secure the I-beam and wall straps. A vertically oriented shaft was welded to the base of the anchor head and two diagonally oriented square tubes were welded to the shaft. Steel rods, up to 1.3 m long, were driven through the diagonal tubes into the ground forming an “X”. However, the crossed rods were designed to be pneumatically driven into solid rock or coral, not unconsolidated soil. Thus, rock anchors were improperly used for securing manufactured homes in Picher. In many instances, anchor heads slipped out of the crossed rod connections as the rods shifted. Steel undercarriages were then rolled or lofted. Within the wreckage of the mangled debris, anchor heads remained intact still strapped to the I-beams (Fig. 14).

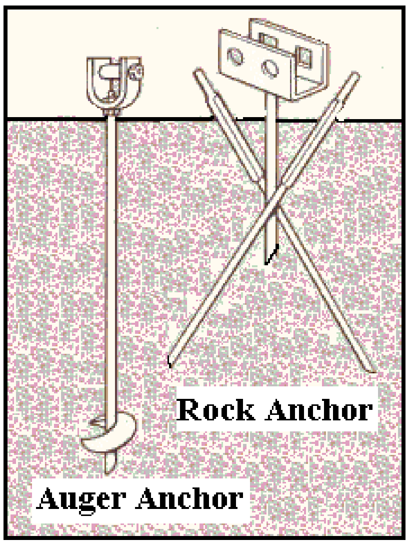


**Figure 13.** Types of anchors that secured manufactured homes in Picher, Oklahoma.

**Figure 14.** Failure of rock type anchor on a manufactured home. The anchor remained strapped to steel I-beam. The inset image show crossed steel rods remained in the ground.

The proper anchor to be used in soil is the auger type. Auger type anchors have a vertical steel rod up to 1.5 m long welded to the base of the anchor head. An auger-shaped disk(s) is welded near the bottom of the rod. Auger anchors are mechanically driven into the ground until the anchor heads are flush with the ground surface. When installed properly, auger anchors provide formidable pull out strength. In Picher, none of the auger anchors had been pulled out of the ground. Instead, failure occurred when the galvanized metal straps broke (Fig. 15).

Galvanized metal straps secured the manufactured homes to the ground. Frame straps extended vertically up the wall framing whereas diagonal straps attached to I-beams that supported the home. The diagonal straps wrapped around the I-beams and were secured with steel buckles. Bottom ends of the galvanized metal straps were inserted into slotted bolts in the anchor heads and tightened.

The galvanized metal straps were 3.2 cm wide and .9 cm thick. According to the U.S. Department of Housing and Urban Development (HUD, 2010), the straps should be capable of resisting a working load of 1432 kg and a 50 percent overload. There were only three instances out of the 66 homes, where the straps held the steel undercarriages in place. However, failures of the homes still occurred when the walls separated from the wood floors or when the wood floors detached from the steel undercarriages.

**Figure 15.** Broken strap on an auger anchor. The inset image shows scrape marks on the strap indicating movement of the steel undercarriage occurred prior to strap failure.

## 4.3 Vehicle Damage

A total of 94 automobiles and “light” trucks were counted within the tornado damage path. Most vehicles had been parked adjacent to homes or along streets. A few vehicles had been parked in garages or carports. Vehicles were checked to see if they had moved laterally, rolled, or been lofted. The degree of vehicle damage was then compared to the DODs of adjacent residences. Refer to Table 3.

Most vehicles (59%) had not moved, and the vast majority (88%) remained upright (Fig. 16). However, flying debris had broken the windows of most vehicles and thus, they would not have been safe havens during the tornado. Rolled, tumbled, or lofted vehicles were rare and limited to areas where houses sustained EF-4 damage.

**TABLE 3**
**COMPARISION OF VEHICLE DAMAGE TO RESIDENTIAL DAMAGE IN PICHER OK**

| EF-rating of nearest house | No vehicle movement | Vehicle shifted laterally | Vehicle rolled or lofted |
|---|---|---|---|
| EF 0 | 9 | 0 | 0 |
| EF 1 | 11 | 0 | 0 |
| EF 2 | 8 | 3 | 0 |
| EF 3 | 3 | 5 | 0 |
| EF 4 | 24 | 25 | 6 |
| **TOTAL** | **55 (59%)** | **33 (35%)** | **6 (6%)** |

**Figure 16.** Most vehicles remained upright in areas where residences sustained EF-4 damage. However, flying debris had broken the windows and thus, vehicles would not have been safe havens in the tornado.

## 5. SUMMARY

The town of Picher, Oklahoma was struck by the first of two long-tracked tornadoes that traveled across northeast Oklahoma and southern Missouri on 10 May 2008. The tornadoes had a total path length of 129 km of which only 2 km went through Picher. Aerial and ground damage surveys were performed after the event. The aerial survey provided a quick overview of the tornado damage path and helped pinpoint areas on the ground for more detailed analysis. It was found that the width of the damage path was consistently 600 m through town with sharp gradations in the degrees of building damage, especially along the north and south edges of the path.

EF-scale numbers were assigned to 166 houses based on the severity of the damage. The maximum damage rating was EF-4. Most homes had concrete masonry pier and beam foundations. Catastrophic failures involved shifting the floor platform off their foundations. Walls failed where they were straight nailed to the bottom plates or where the bottom plates were straight nailed to the floors. Such failures continue to be common with wood-framed homes. The fact that poorly built and unanchored homes were swept clean from their foundations did not indicate EF-5 winds. Homes constructed on concrete slabs also had walls nailed improperly to the foundation perimeters.

There were 66 manufactured homes within the tornado path of which 73 percent were destroyed. Most of manufactured homes had been secured improperly to the ground with rock anchors instead of auger anchors. Anchor heads were removed from the crossed rod connections. Auger anchors remained in place but the straps securing the homes had broken. Thus, manufactured homes were destroyed regardless of the types of anchorage used.

It was found that 88 percent of vehicles remained upright even where the most intense damage occurred. However, flying debris breached the vehicles rendering them unsafe for occupancy during the tornado. Rolled, tumbled, or lofted vehicles were rare and limited to areas where houses sustained EF-4 damage. Similar observations were made during the authors’ surveys of tornado damage at Parkersburg, Iowa and Greensburg, Kansas. Yet, smaller tornadoes, like the one that tossed vehicles in a parking lot in Leighton, Alabama on 9 May 2008, bring up continuing questions about vertical velocities in tornadoes.

**ACKNOWLEDGEMENTS**

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