Roof Instability

What Reportable Noninjury Roof Falls in Underground Coal Mines Can Tell Us

By T.S. Bajpayee, Deno M. Pappas and John L. Ellenberger

Ground falls have historically been responsible for nearly 50% of all fatalities in underground bituminous coal mines (Mark, Pappas & Barczak, 2009). Roof bolting in coal mines began on a modest scale in the early 1950s. Since then, the design of bolts, grout systems, accessories and installation techniques has improved significantly. Currently, roof bolting is the primary means of supporting mine roof in room-and-pillar operations in the bituminous coal sector. Although roof support systems have improved greatly, roof falls continue to occur in bolted areas. Design and maintenance of adequate support systems is essential for ensuring ground stability and preventing roof falls. (Note: The term *roof falls* is used synonymously with *falls of roof* and *falls* in this article.)

Coal mine operators must report two types of roof falls to MSHA: 1) falls causing injury to workers; and 2) noninjury falls in active areas that impair ventilation, impede passage of miners or extend at least to the anchorage zone of roof bolts. Most injury-causing roof falls involve falls of small chunks of roof rock from the immediate roof beam (Robertson & Hinshaw, 2002). MSHA (2010) data indicate that noninjury roof falls are often large and could comprise an entire intersection or extend to an entire pillar length.

The large body of noninjury roof fall reports provides an opportunity to gain insight into the characteristics of roof falls in coal mines. The results will help direct research and development for improving roof support systems. This study was designed to identify geological contributors to roof falls, the relationship between length of bolts and the height of roof fall cavities, and the distribution of roof falls in different coalbeds and mining regions in the U.S. This study included data from approximately 11,600 noninjury roof fall incidents reported to MSHA by more than 800 mines from 1999 through 2008.

Study Methods

MSHA collects incident, injury, employment and production data for the mining industry. NIOSH (2010) converts these data to SPSS and dBase IV file formats, and maintains these files on its website. For this study, the researchers retrieved relevant roof fall information from the NIOSH website.

The primary source of information for this study was operator sector data on

IN BRIEF
- **Roof falls are a major hazard in underground mining. Roof bolting is the primary means of supporting the mine roof in underground coal mines. Despite great strides in the design of support systems, roof falls continue to occur in bolted areas.**
- **Noninjury roof fall reports provide insight into the characteristics of roof falls.**
- **This study examined 11,600 noninjury roof fall reports to identify geological contributors to roof falls. The goal is to provide data that can help improve roof-fall-related safety by providing direction for the research and development of improved support systems and mine layout alternatives.**

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Figure 1

Noninjury Roof Falls

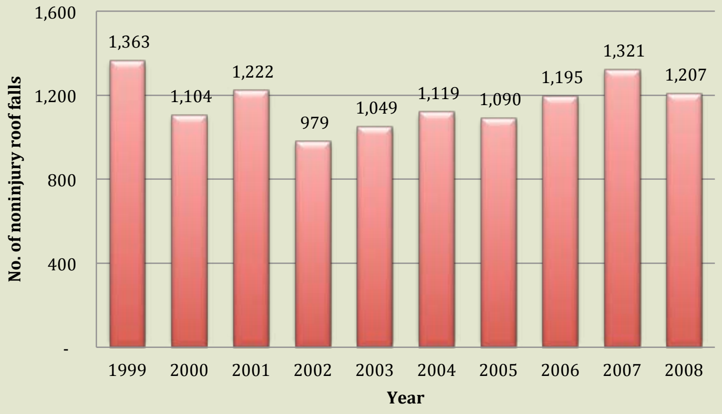


Figure 1 shows the annual distribution of noninjury roof falls, 1999-2008. The count remained consistent over the study period.

roof falls in room-and-pillar operations at underground bituminous coal mines from 1999 through 2008. The study findings are limited to the information reported to MSHA as well as data available on the NIOSH website. Furthermore, various NIOSH publications provided supplemental information to augment this research. In addition, Part 50 Data User's Handbook (MSHA, 2007) helped the authors understand the codes and retrieve necessary information. The narratives associated with roof fall incidents were examined to understand the contributing factors involved in the reported case. Although mine operators are not required to list contributory factors, these data are often reported in the narratives, which offer brief summaries that typically identify the location and size of the falls and may provide other information.

Results & Discussion

The results presented in this article relate to reportable noninjury roof falls that extended at least to the anchorage zone of roof bolts, impaired ventilation or impeded passage of miners.

Figure 2

Average Roof Falls

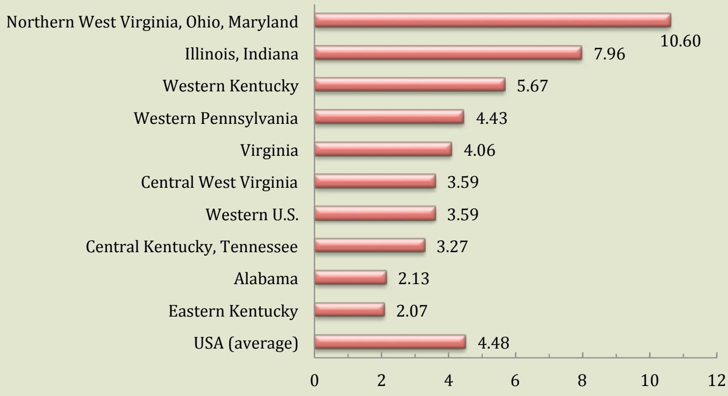


Figure 2 shows the average roof fall per 200,000 employee-hours reported for each U.S. coal mining region, 1999-2008.

Annual Roof Fall Count

Figure 1 shows the annual distribution of approximately 11,600 noninjury roof fall incidents reported from 1999 through 2008. The annual roof fall count remained relatively consistent over the study period, ranging from 979 and 1,363, with an average of 1,160 falls per year.

Distribution of Roof Falls at Various Coal Mining Regions in the U.S.

MSHA (2007) has 10 regional offices whose staff inspect operations at bituminous coal mines: 1) western Pennsylvania; 2) northern West Virginia-Ohio-Maryland; 3) central West Virginia; 4) Virginia; 5) eastern Kentucky; 6) central Kentucky-Tennessee; 7) Illinois-Indiana; 8) western Kentucky; 9) western U.S.; and 10) Alabama. The Illinois Coal Basin comprises Illinois-Indiana and western Kentucky mining regions. Roof fall data were analyzed to study the distribution of roof falls in these 10 regions.

The average number of roof falls per 200,000 employee-hours for each region was calculated based on the number of roof falls and the employee-hours of the region. Furthermore, the average number of roof falls per 200,000 employee-hours for the U.S. was calculated to determine the national average. Roughly 200,000 employee-hours correspond to the number of hours worked by 100 full-time miners in a year.

Figure 2 plots the number of roof falls per 200,000 employee-hours for the various regions. The northern West Virginia-Ohio-Maryland region experienced the highest roof fall rate followed by the Illinois-Indiana and western Kentucky regions. Pappas and Mark (2012) also reported a higher noninjury roof fall rate for the northern West Virginia-Ohio-Maryland region. The Illinois-Indiana and western Kentucky regions can be considered as a single group because both are located in the Illinois Coal Basin. The roof fall rate in the Illinois Coal Basin is higher than the national average rate of 4.48—7.96 in the Illinois-Indiana region and 5.67 in the western Kentucky region.

Table 1 lists the number of roof falls (*N* = 4,393) for the top 26 individual mines arranged in descending order. The fall count was not normalized by production rate or hours worked; instead, the table simply lists the falls per mine operation during the study period (1999 through

2008). These 26 mines, which represent about 3.2% of the reporting mines, were responsible for 37.7% of all reported roof falls. Figure 3 (p. 60) shows the region-wise distribution of these 26 mines, 18 of which are located in the the Illinois Coal Basin.

Height of Roof Fall Cavity Above Roofline & Bolt Anchorage Zone

Roof falls with a cavity height of 2 ft or less are considered skin failures (Tadolini & Dolinar, 2001). Noninjury roof falls reviewed for this study were generally larger than skin failures. Pertinent cavity height information was obtained from the incident narratives. Cavity height above the roofline was available for 5,514 falls (Figure 4, p. 61). The cavity height of 33.9% of falls ranged from greater than 4 to 6 ft and 29.8% ranged from greater than 6 to 8 ft. The cavity height of 11.1% of falls exceeded 10 ft. In coal mines, roof bolts are commonly 4 to 6 ft in length.

The height of roof fall cavity above the anchorage zone of roof bolts was available for 2,205 cases. Figure 5 (p. 61) shows the distribution of cavity height above the bolt anchorage zone for the cases where the cavity height exceeded bolt length. The height of roof fall cavity of 69% of falls was within 2 ft of the bolt anchorage zone. This result confirms that bolts are successful at controlling the roof when the height of unstable ground is less than the bolt length. However, collapse can occur when preexisting conditions or time-related weakening of the rock exceeds the bolt length.

Coalbeds Susceptible to Roof Falls

The researchers attempted to examine the distribution of roof falls in different coalbeds to understand whether certain coalbeds were more susceptible to roof falls. A coalbed including its roof layers has a unique set of geological characteristics that can influence roof stability. A coalbed (also known as a coal seam) is a geological deposit of coal occurring below ground.

The coalbed codes (unique identifier of a coalbed) and associated local names were obtained from the Energy Information Agency (EIA) database of the U.S. Department of Energy. Local names listed in NIOSH's database were matched and merged with the local names and codes listed in the EIA database. (In a geographical area, a coalbed is often recognized by its local name. Local names of a coalbed may change from one geographical area to another.) Researchers identified 96 coalbed codes accounting for 10,164 (87.25%) roof falls. It is interesting to note that eight coalbed codes (of the 96 identified codes) accounted for 5,744 (56.5%) roof falls.

Table 2 (p. 62) lists the regional distribution of roof falls (*N* = 5,744) associated with these eight codes. Code 76 represents the highest roof fall rate per 200,000 employee-hours, followed by codes 489 and 484. Code 76 is known locally in western Pennsylvania as the Kittanning coal seam; it is mined in other states as well, including Ohio, Maryland and West Virginia. The roof is generally weak due to the presence of slip planes, slickensides, clays and siltstones (Iannacchione & Puglio, 1979). In such situations, the solution is generally to increase the intensity of supports. Longer roof bolts, roof screen, straps and cable bolts are also employed to provide supplementary support and maintain safe conditions.

Coalbed codes 489 and 484 are located in the Illinois Coal Basin. They accounted for 2,812 roof falls—1,815 in the Illinois-Indiana region and 997 in the western Kentucky region. Molinda, Mark, Pappas, et al. (2008), reported that weak, moisture-sensitive roof and horizontal stress contribute to the high roof fall rate in this basin, which presents some of the most challenging roof control issues in the U.S. Solutions include applying spray-on sealants to limit rock exposure to moist air, drainage of water and applying roof screening to control damaged rock. Other more traditional approaches include installing longer roof bolts and adding straps to the support system.

Identifying Contributory Geologic Factors From Narratives

Many of the incident narratives examined lacked the information needed to draw meaningful conclusions relative to the contributing geologic factors. However, the researchers found well-documented narratives for 1,825 incidents and used these to group contributory geologic factors into seven categories.

Table 1

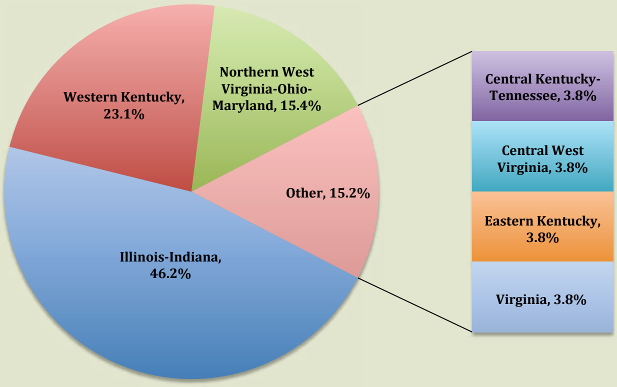
Noninjury Roof Falls Reported by the Top 26 Mines

Rank	Mine	Location	Roof falls
1	Mine 1	Northern West Virginia-Ohio-Maryland region	539
2	Mine 2	Illinois-Indiana region	336
3	Mine 3	Western Kentucky region	327
4	Mine 4	Illinois-Indiana region	300
5	Mine 5	Illinois-Indiana region	260
6	Mine 6	Northern West Virginia-Ohio-Maryland region	254
7	Mine 7	Illinois-Indiana region	201
8	Mine 8	Illinois-Indiana region	191
9	Mine 9	Illinois-Indiana region	160
10	Mine 10	Western Kentucky region	150
11	Mine 11	Illinois-Indiana region	148
12	Mine 12	Western Kentucky region	140
13	Mine 13	Illinois-Indiana region	137
14	Mine 14	Western Kentucky region	131
15	Mine 15	Illinois-Indiana region	119
16	Mine 16	Central Kentucky-Tennessee region	105
17	Mine 17	Central West Virginia region	105
18	Mine 18	Northern West Virginia-Ohio-Maryland region	97
19	Mine 19	Northern West Virginia-Ohio-Maryland region	96
20	Mine 20	Western Kentucky region	95
21	Mine 21	Eastern Kentucky region	94
22	Mine 22	Illinois-Indiana basin	90
23	Mine 23	Western Kentucky region	86
24	Mine 24	Virginia region	84
25	Mine 25	Illinois-Indiana region	78
26	Mine 26	Illinois-Indiana region	70
		Total	**4,393**

Note. *Data from accident, illness and injury and employment self-extracting files (Part 50 data). Retrieved from* **www.msha.gov/ACCINJ/accinj.htm**

Figure 3

Region-Wise Distribution of Mines Listed in Table 1



Slip in the Roof

The slip in the roof category primarily includes slip in the roof rock above the roof level. Presence of slick rock and slickenside-rock in the roof layers are also included. When two slips intersect at an obtuse angle above the roof level, a roof fall may occur. Often, these slips were identified only after the roof fall had occurred. In such circumstances, mine operators generally reported that the roof fall had occurred due to the presence of an undetected or unexpected slip in the roof.

Prominent geological discontinuities usually create a sliding surface and thereby weaken the rockmass's overall strength. Differential movement of rock layers on a slip surface occurs due to stress readjustment caused by mining. A slickenside, slip or shear is actually a failure surface on which there has been lateral movement of shale or other clay-rich rocks (Molinda, 2003). In the narratives, slip was found to be the primary contributing factor most frequently associated with roof failure (Figure 6, p. 62).


C. MARK/NIOSH

Photo 1: Failure of laminated roof layers in a coal mine.

Laminated Roof

Presence of thin laminations in a weak roof beam can contribute to entry failure. Laminations in the roof beam cause it to be subdivided into multiple thin beams. Weak, thin beams tend to separate and deflect downward into the mine entry. In addition, mining-induced stress could initiate progressive shear failure in thin layers of roof beam (Iannacchione, Esterhuizen, Bajpayee, et al., 2005). The interface material between adjacent layers may fail as well, causing differential movement in the layers and thereby weakening the overall rockmass strength. In the narratives, the presence of laminations in the immediate roof beam was reported as the second largest contributory factor for roof falls (Figure 6). Photo 1 shows failure of laminated roof in a coal mine (Esterhuizen & Bajpayee, 2012).

Draw Rock

Draw rock (also known as draw slate, draw shale and stack rock) is a shale or mudstone unit that lies immediately above the coal bed and is too weak to be self-supporting, thus tending to fall when coal is mined. It deteriorates due to exposure to moisture or water percolating through the roof. Stack rock is a sequence of rock composed of interbedded sandstone and shale; it is often associated with weak or poor-quality roof. Stack rock may be strong axially depending on the proportion of sandstone in the mix, but is typically weak along the bedding planes and could fail under high horizontal stress (Molinda, 2003). Draw rock is the third largest contributory factor associated with roof falls (Figure 6).

Wet Roof

The wet roof category includes water in roof, percolation in roof and moist roof. Water tends to weaken the bonding between roof layers, particularly in roofs containing shale, clay and mud rock. Additionally, several roof rocks in the Illinois Coal Basin are moisture sensitive and often degrade when exposed to water (Molinda, 2003). Water percolating from roof induces swelling and loss of strength in many poorly jointed shale rocks. The process is progressive and eventually results in roof failure. Wet roof is the fourth largest contributory factor associated with roof falls (Figure 6).

Rider Seam

Rider seam and rider coal have been reported synonymously in the database. Rider seams are minor coalbeds deposited over a thicker coalbed (Molinda, 2003). The thickness of rider coal often ranges from several inches to a few feet. Shales with a high carbonaceous content or coal streaks above the roof horizon have often been reported as rider coal. Rider coalbeds are weak. Rider coal just a few inches thick over the anchorage zone of roof bolts could initiate roof failure. Rider coal is the fifth largest contributory factor for roof falls (Figure 6).

Clay

During the coal formation period, silt and clay were deposited parallel to the bedding plane or even injected across the bedding at an angle. Clay veins usually reduce the overall strength of the roof rock and may initiate roof failure. Molinda (2003) reported occurrences of roof problems due to clay veins in Pennsylvania and central Illinois. The incident narratives reviewed listed presence of clay in the roof rock as a contributory factor for numerous roof falls.

Cutter

The cutter category also includes roof falls due to the presence of high horizontal stress. Horizontal stress associated with poor rock quality is known to have initiated cutter failure in the Illinois Coal Basin (Molinda, 2003). (In this context, the word *cutter* is synonymous with the term *gutter* or *roof gutter*.) Fur-

G.M. MOLINDA/NIOSH

Photo 2: Initiation of roof cutter in a coal mine.

thermore, when the horizontal stress exceeds the vertical stress, it may cause cutter failure. Photo 2 shows initiation of roof cutter in a coal mine (Esterhuizen & Bajpayee, 2012). No unique solution exists for controlling or avoiding cutter roof failure (Hill, 1986). Even at shallow depths, horizontal stress is a concern for entry stability. Mark and Mucho (1994) and Su and Hasenfus (1995) reported that horizontal stress is often higher than the vertical stress in coal-bearing rock formation.

Interestingly, three factors—slip, laminated roof and draw rock—were reported to be associated with about 75% of 1,825 roof fall incidents that included geologic factors in the narratives. In operating mines, the solution to these unfavorable geological factors includes the installation of supplementary support or modification of the mining layout.

A well-known approach to improve roof stability is to simply reduce the width of the excavations. Other techniques may be to reorient the direction of mining so that it is more favorable relative to the major horizontal stress (Mark & Mucho, 1994). Supplementary supports in the form of additional roof bolts, straps or screen (chain-link or welded steel mesh) may be installed to increase the areal coverage of the supports. Installing longer roof bolts or cable bolts is very effective, especially if the longer supports are able to anchor in stronger layer.

Conclusion

Falls of roof continue to be a major hazard in underground coal mining. This study examined 11,600 reportable noninjury roof falls that occurred from 1999 to 2008 in room-and-pillar operations in the bituminous coal sector. An average of 1,160 falls were reported per year during the study period. Key findings include the following:

•Coal beds mined in the Illinois Basin region are susceptible to roof falls. In this region, roof instability is associated with moisture sensitivity of the weak shale roof rocks and horizontal stress related damage.

•The geological structures most commonly mentioned in the roof fall narratives were slips, laminated roof and draw rock. Timely identification of the presence of these structures can help to ensure that appropriate supports are installed to control their negative effects on roof stability.

•About 70% of roof fall cavities extend no more than 2 ft above the bolted horizon. This finding confirms the effectiveness of bolting in providing support to the rock within the bolted horizon. It also seems to indicate that roof deterioration occurs over time and collapse can occur when the weakened roof has progressed beyond the length of the bolts.

The study has highlighted the coal-producing regions and geological issues related to high roof fall rates in underground coal mines. These results can be used to direct research, support technology development and mine layout alternatives. **PS**

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Figure 4

Roof Fall Cavity Height Above Roof Level

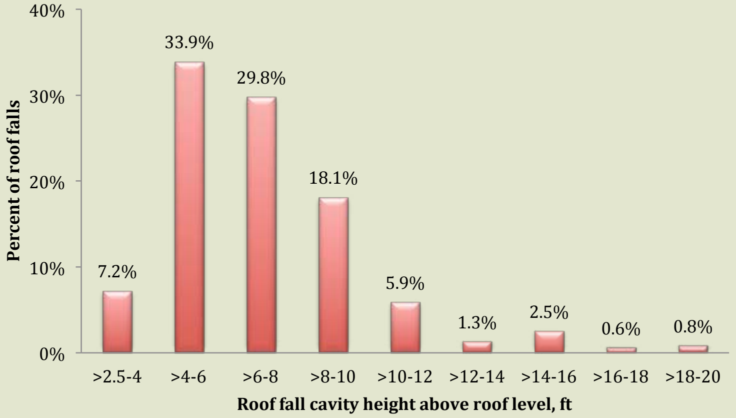

Figure 5

Roof Fall Cavity Height Above Bolt Anchorage Zone

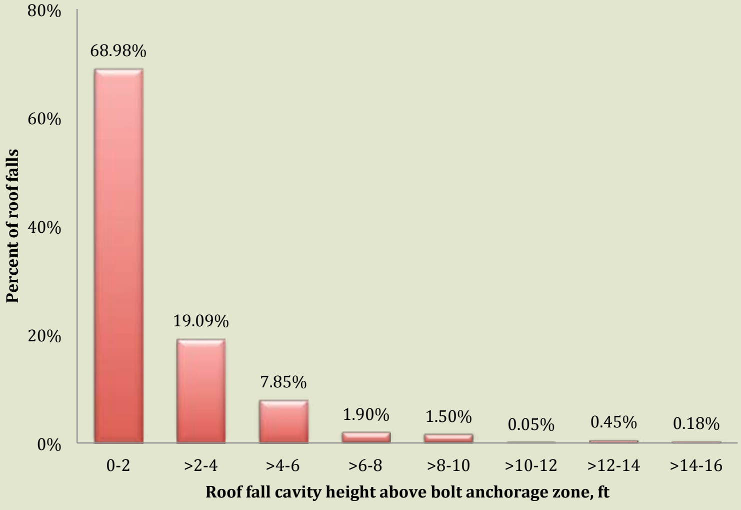

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Table 2

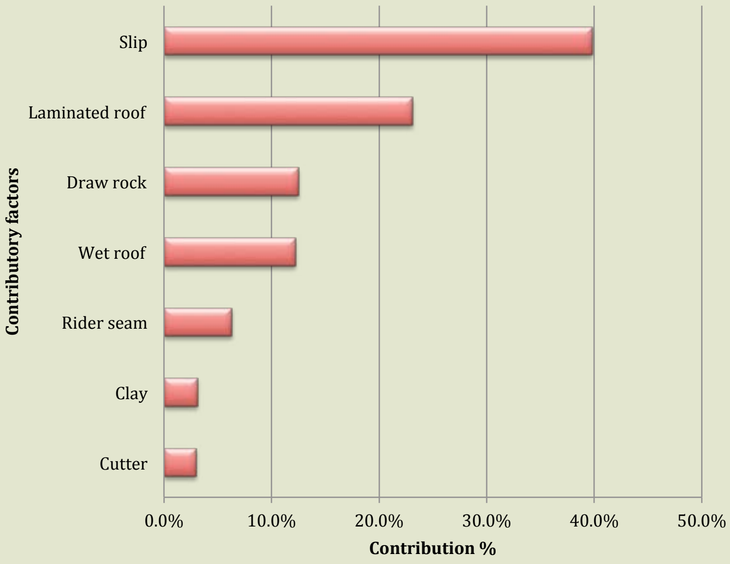
Regional Distribution of Roof Falls, Top Eight Coalbed Codes

Roof fall rank	Coalbed code	Western Pennsylvania region	Northern West Virginia-Ohio-Maryland region	Central West Virginia region	Virginia region	Eastern Kentucky region	Central Kentucky-Tennessee region	Illinois-Indiana region	Western Kentucky region	Total	Roof falls per 200,000 employee-hours
1	489							1,045	947	1,992	7.58
2	484							770	50	820	6.85
3	76	116	448	1						565	12.08
4	151			61	36	187	258			542	2.63
5	168			160	20	347	2			529	3.32
6	135			4	23	84	331			442	3.12
7	111			338	8	52	41			439	4.49
8	84	160	131	124						415	5.73
Total		**276**	**539**	**688**	**87**	**670**	**632**	**1,815**	**997**	**5,744**	**5.19**

Note. *Data from accident, illness and injury and employment self-extracting files (Part 50 data). Retrieved from* **www.msha.gov/ACCINJ/accinj.htm**

Figure 6

Contributory Factors Leading to Roof Fall



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