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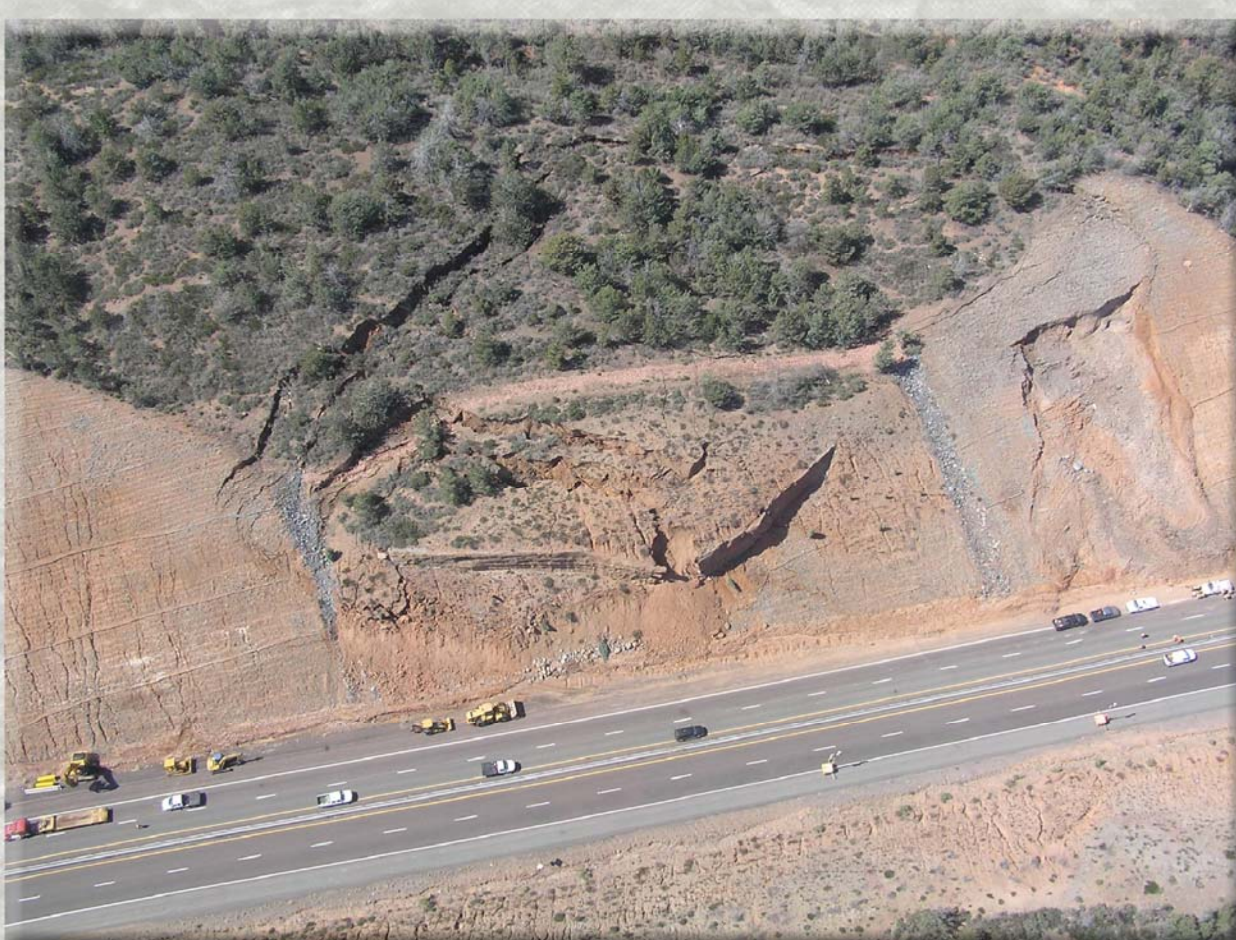

Reconnaissance Report on the Easter Weekend Landslide of 21 March 2008, SR-87, Gila County, Arizona

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ARIZONA GEOLOGICAL SURVEY

Abstract

A series of small earth movements occurred along the slopes of State Route 87 at about mile marker 224 (between the Bush Highway and Route 188) throughout the winter of 2007-2008, culminating with a landslide on Friday, 21 March 2008. This landslide buckled the southbound lanes, displaced the northbound lanes, and closed the highway for nearly a week. The mass movements occurred on slopes that were constructed with re-vegetated, laid back slopes; soil nail walls; and rip rap-lined channels. However, our reconnaissance mapping indicates that most, if not all, of the slope movements are located within a much larger, older landslide adjacent to, and cut by, SR-87. No specific trigger for the landslides was immediately apparent, although a combination of factors (e.g., precipitation, groundwater levels, etc.) may have contributed to conditions for the slope failure. Headscarps of various types of landslides are present along both sides of the highway. Results from our preliminary investigation indicate that up to three other paleo-landslides may be present in the immediate vicinity. The full extent and nature of these landslides are unknown and require further investigation to evaluate their potential to be reactivated and risk they pose to the highway.

Introduction

On 21 March 2008, a landslide occurred at about mile marker 224 on State Route 87 (SR-87) (northeast of Iron Dike mountain), in Gila County, causing sufficient damage to require the highway to be closed for six days while cleanup and mitigation efforts were underway. Several other slope failures in the vicinity have occurred at least since 2005, and most recently during winter 2007-2008.

In the mid-1990s, the Arizona Department of Transportation (ADOT) contracted with the United States Geological Survey (USGS) to map a portion of the Kitty Joe Basin as part of the geotechnical investigation of the new alignment for SR-87. The USGS (Conway, 1995) produced a map and report characterizing the geology of the area. Conway indicated the presence of two landslides adjacent to the area of the 21 March slope failure, but based on his mapping neither landslide crossed SR-87 (Figure 1). Conway addressed the landslides in his report, however, stating that further investigation should be made of the landslides prior to building a road through the area. ADOT completed the new route in 2000.

In accordance with Arizona Revised Statute (ARS) 27-52, the Arizona Geological Survey (AZGS) began a preliminary reconnaissance of the landslide events on 23 March 2008. The statute directs AZGS to "map, describe, and monitor known and potential geologic hazards and limitations to land and resource management," and to "provide technical advice and assistance in geology to other state and local governmental agencies engaged in projects in which the geologic setting, character, or mineral resources of the state are involved."

We summarize our findings below. In this report, the term "Easter weekend landslide" refers to the landslide that buckled the highway on 21 March; the term "winter 2007-2008 landslides" refers to slope failures occurring along both sides of the highway in this area; and the term "paleo-landslide" refers to the older, larger landslide mass in which the Easter weekend landslide and the winter 2007-2008 landslides occurred. We labeled this group of landslides the

"Iron Dike landslides" after Iron Dike Mountain, a prominent peak located three-quarters of mile southwest of the Easter weekend landslide (Figure 1).

Figure 1 Regional aerial photographic map showing probable extent of landslide deposits as mapped by Conway (1995).

Within the limits of the constricted right of way for the SR-87 alignment, ADOT constructed a new highway alignment with re-vegetated, laid-back slopes; soil nail walls; and rip rap-lined drainage channels. ADOT has had to perform continual maintenance on the slopes, and in 2005, two of the soil nail walls failed. Prior to the Easter weekend landslide, ADOT had initiated a geotechnical investigation of the site, which they escalated after the landslide occurred.

Figure 2. Slope failures that occurred during winter 2007-2008 near mile marker 224. **A.** The southern-most landslide on the west side of the highway; note the broken shotcrete (white arrows). The metal fence in the foreground is the median of the highway; the Jersey barriers behind the fence are on the shoulder of the southbound lane, separating the highway from debris. **B.** Slope failure (inside yellow ellipse) in material from an older landslide on the east side of SR-87. Scarps are present above the highest tier of soil nail walls; material is moving down slope over both walls. Photos taken on 23 March 2008 (A) and 25 March 2008 (B) by M. Diaz.

Data from the Maricopa County Flood Control District's ALERT precipitation gage on Mt. Ord (5960), approximately 2.5 miles east-southeast of the landslide, provides an estimate of precipitation in the landslide area during the winter of 2007-08. This gage recorded 14 inches of precipitation between 1 October 2007 and 21 March 2008, when the main landslide occurred (Appendix A). Smaller mass movements occurred on both the western (Figure 2A) and eastern (Figure 2B) slopes throughout the winter of 2007-2008, prompting ADOT to place protective barriers (k-bars or Jersey barriers) between the western slope and the highway. Ironically, the gage recorded only 0.24 inches of rain between 1 March and 21 March; this fell in about a 75-minute period on 17 March. This rain event may have caused the pore pressure to exceed stable limits, thereby increasing the pressure against the soil nail walls and decreasing the shear strength of the materials within the paleo-landslide mass.

Figure 3 A. Close-up of the lower part of the landslide buckling the highway. **B.** The landslide displaced the road and divider about 1 foot to the east. Both views looking north. Photos taken on 23 March 2008 by B.F. Gootee.

On 21 March, sections of the western slope failed in a larger landslide. Based on displaced material and the buckling of SR-87 southbound lanes, it appeared that some of the northern part of the slide plane extended under the highway (Figure 3A). The southbound lanes of the highway were buckled and broken, for approximately 50 feet along the length of the highway. One section of the freeway was buckled up to approximately 3 feet in height (Figure 4). The median was displaced about 1 foot eastward (Figure 3B), and the northbound lanes buckled to a lesser extent than the southbound lanes. Contractors doing emergency repairs reported that the buckled section fluctuated vertically for at least five days afterward.

Figure 4 The Easter weekend landslide pushed up the highway, deforming both south- and northbound lanes. The southbound lanes (shown here) buckled approximately 3 feet high and 50 feet along the length of the highway. View is to northwest. Photo taken on 23 March 2008 by M. Diaz.

Geology and Geomorphology

The geology of the area surrounding the Iron Dike landslides (Cottonwood Basin, central Mazatzal Mountains) consists of Cenozoic volcanic and basin fill deposits overlying Proterozoic metamorphic and igneous rocks (Conway, 1995), with limited Quaternary surficial deposits. The Tertiary basin-fill sequence consists primarily of clay-rich, sandy gravel. Basalt flows cap the topographic highs and are intercalated with basin fill deposits. Surficial deposits include basalt colluvium and alluvium. Conway (1995) infers a west-downward fault immediately to the south of Iron Dike with basalt and basin-fill deposits offset, although there is no clear evidence for Quaternary fault activity in the area (Pearthree, 1998; Pearthree and Bausch, 1999).

Figure 5 Unsorted, matrix-supported clastic material that is suggestive of a debris flow deposit (top) above moderately indurated, bedded basin-fill deposits along one of the drainages at the downslope exposure of the landslide. Note the irregular erosional surface below the deposits in the wall of the outcrop. Photo taken on 28 March 2008 by M. Diaz.

A large, complex paleo-landslide developed on the northeast flank of Iron Dike Mountain sometime during the Quaternary. The head of this paleo-landslide is approximately 1500 feet wide, with a possible runout of nearly one mile (this investigation). The scarps (head and minor) are steep but scarp crests are rounded, and the main body is heavily vegetated. Drainages dissect the probable toe and interior, and may define the lateral extent. Old debris flow levees and snouts, which are the termini of debris flows, (with clasts ranging from cobbles to boulders, some of which are nearly 3 feet in diameter) are covered with moss and lichens; the original matrix has been scoured away and the resultant cavities are being refilled with sediment from overland flow. These debris flows are present at the inferred toe of a paleo-landslide deposit on the east side of the highway (Figure 5). They may have contributed to headward erosion and the formation of drainages that further dissect the slide(s). Some of the drainages show evidence for two to three pulses of debris flows. All of this evidence suggests that the large landslide complex is fairly old, although parts of the complex may have been active fairly recently.

Figure 6 Portion of the Easter weekend landslide that damaged the highway. Note pavement, gray artificial fill under the pavement, and red, clay-rich, moist sediment under the fill. Photo by B.F. Gootee, 23 March 2008.

The main body of the paleo-landslide (and thus the Easter weekend landslide) is composed of clayey sand and sandy clay; however, areas within the body of the paleo-landslide contain mostly clay with lenses and beds of sand. The volume of clay present varies from nearly 100% at the probable failure plane of the Easter weekend landslide (Figure 6) to <5% near the surface. The interior of the landslide is deformed in places, with sheared surfaces (Figure 7A) and slickensides (Figure 7B) present, and undeformed in other places (with the bedding preserved and only the dip direction changed). It is unclear whether the Easter weekend landslide, the paleo-landslide, or some combination of the two caused the slickensides. At the time of our investigation, the entire slide mass was moist below depths of approximately 2 inches. Soil and colluvium are present on the surface of the slide; it is unclear whether the soil developed since the paleo-event or if the soil has moved with the landslide.

Figure 7 A. Example of internal shearing within the slide mass (head scarp on the east side of the highway). White dashed lines indicate sheared features; white arrows indicate direction of relative motion. Similar structures are also visible in the Easter weekend slide mass on the west side of the highway. **B.** Slickensides observed in the interior of the landslide (on the west side of the highway) indicate shearing in the clayey gravel. Photos taken on 28 March 2008 (A) and 23 March 2008 (B) by B.F. Gootee.

Preliminary investigations indicate that several other paleo-landslides exist in the area of the Easter weekend landslide. Examination of topographic maps, digital elevation models (DEMs), and aerial photography revealed that SR 87 may cross at least three other older landslides in the immediate vicinity (Figure 9). Questions also remain as to how many landslide events have occurred within the paleo-landslide deposits: did they form in fairly discrete events, or did movement occur in stages? The extent and exact nature of all four of these landslides are unknown and require further investigation.

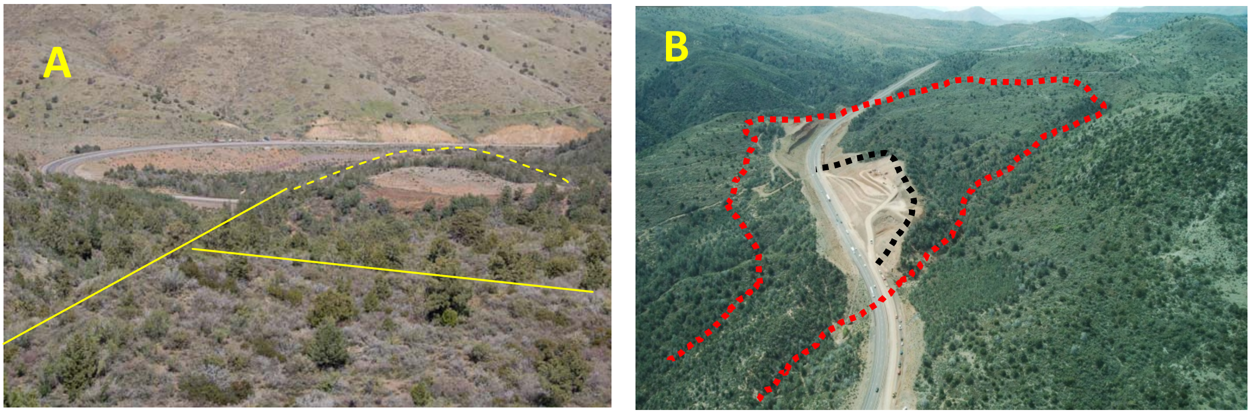

Figure 8 A. View NE from headscarp of paleo-landslide, looking down the direction of sliding. It appears that the paleo-landslide mass extrends across SR-87. . Yellow lines indicate sharp slope breaks; dashed where inferred or out of the photo's viewshed. **B.** Aerial view to the south Inferred extent of paleo-landslide in red; dashed black line represents Easter weekend landslide. Photos taken on 23 March 2008 (A) and 7 April 2008 (B) by B.F. Gootee.

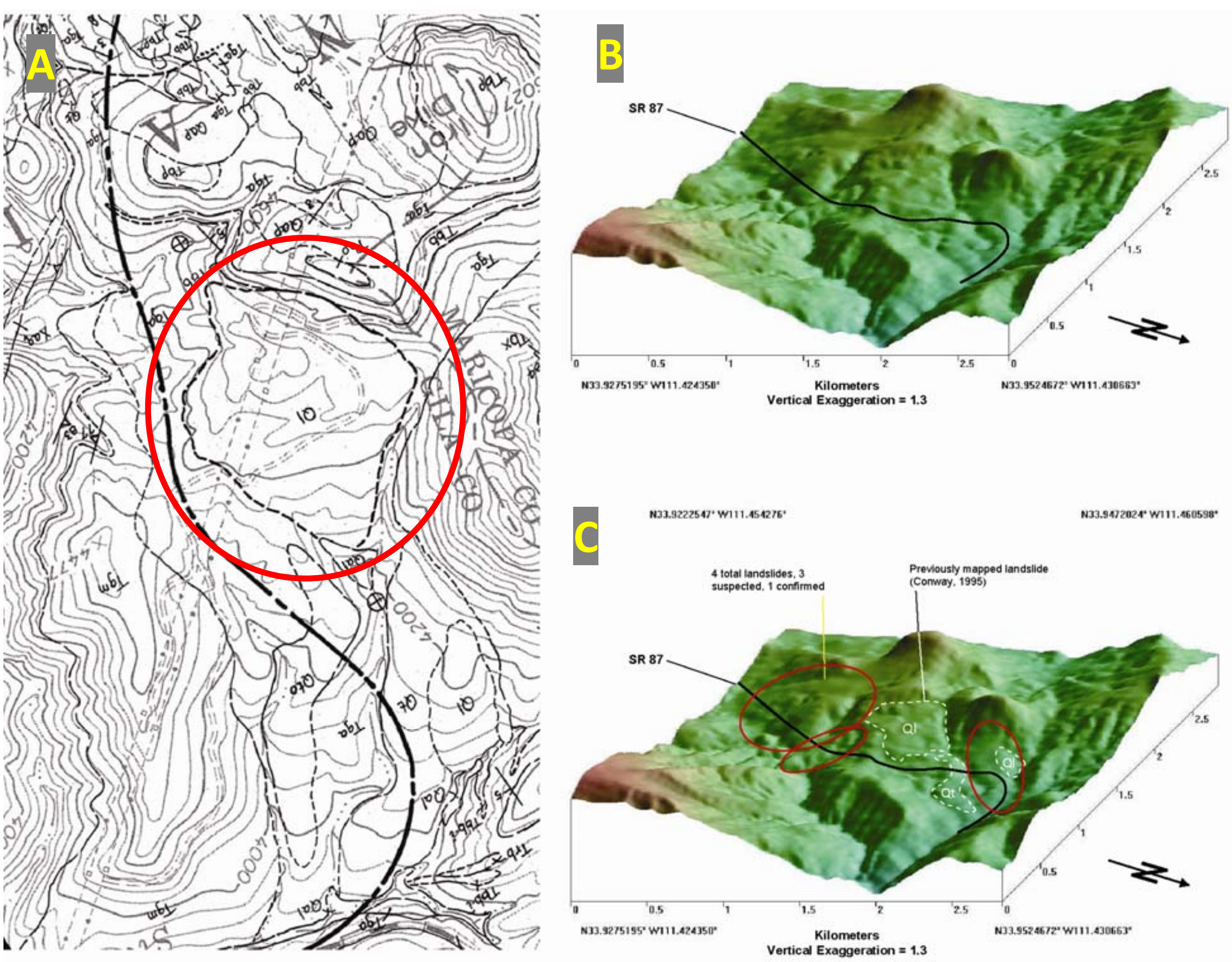

Figure 9 A. Geologic map from Conway (1995); the unit labeled Ql is the main body of the paleo-landslide (inside the red circle). The map has been rotated (north to bottom of figure) so that the view is the same as in the digital elevation models (DEMs) to the right (**B** and **C**). Geomorphic features suggest at least four paleo-landslides may have occurred in this area (red ellipses and white dashes on C showing approximate locations) and cross SR-87. Iron Dike Mountain is the highest elevation point shown in the DEM.

Conclusions and Recommendations

The landslides that occurred during the winter of 2007-2008 and culminated with the closure of SR-87 after the Easter weekend landslide on 21 March 2008 were part of a larger, older complex of landslides radiating from Iron Dike Mountain and its adjacent ridges. It is possible that the highway cuts through the deposits of up to four old landslides that had not previously been recognized. There are several knowledge gaps that need to be addressed in order to facilitate the development of mitigation strategies, including:

- extent and nature of the Easter weekend landslide;
- the depth of the slide plane(s);
- additional types of motion that can be expected;
- time since last movement of the Iron Dike landslide complex;
- verification of other paleo-landslides in the area;
- the number of landslides that may impact the highway;
- how many landslide events occurred and what their temporal relationships are; and
- whether there are portions of the basin fill sequence that are particularly susceptible to mass wasting that should be evaluated with respect to other sections of the highway.

Acknowledgements

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Cover photo by Keith Dahlen.

References

Conway, C.M., 1995. Geology of the Kitty Joe Canyon area, Mazatzal Mountains, Arizona (report prepared for Arizona Department of Transportation), US Geological Survey.

Pearthree, P.A., 1998. Quaternary fault data and map for Arizona: AZ Geological Survey Open-File Report 98-24, 122 p. scale 1:750,000.

Pearthree, P.A., and Bausch, D.B., 1999. Earthquake hazards map: AZ Geological Survey Map 34, scale 1:1,000,000.

Appendix A:

Precipitation data from the Maricopa County Flood Control District Mt. Ord ALERT rain gage approximately 2.5 miles east-southeast of study area (http://156.42.96.39/showrain.html).

FCDMC ALERT System Data Display			
5960 Mt. Ord Precipitation Gage			
Date	Time	Cumulative Precip (in)	Storm total (in)
3/21/2008	9:20:19	14.33	0.00
3/21/2008	6:20:16	14.33	0.00
3/21/2008	3:20:16	14.33	0.00
3/21/2008	0:20:16	14.33	0.00
3/20/2008	21:20:17	14.33	0.00
3/20/2008	18:20:17	14.33	0.00
3/20/2008	15:20:17	14.33	0.00
3/20/2008	12:20:17	14.33	0.00
3/20/2008	9:20:17	14.33	0.00
3/20/2008	6:20:18	14.33	0.00
3/20/2008	3:20:18	14.33	0.00
3/20/2008	0:20:18	14.33	0.00
3/19/2008	21:20:21	14.33	0.00
3/19/2008	18:20:18	14.33	0.00
3/19/2008	15:20:19	14.33	0.00
3/19/2008	12:20:19	14.33	0.00
3/19/2008	9:20:19	14.33	0.00
3/19/2008	6:20:19	14.33	0.00
3/19/2008	3:20:20	14.33	0.00
3/19/2008	0:20:20	14.33	0.00
3/18/2008	21:20:20	14.33	0.00
3/18/2008	18:20:27	14.33	0.00
3/18/2008	15:20:20	14.33	0.00
3/18/2008	12:20:21	14.33	0.00
3/18/2008	9:20:21	14.33	0.00
3/18/2008	6:20:21	14.33	0.00
3/18/2008	3:20:21	14.33	0.00
3/18/2008	0:20:22	14.33	0.00
3/17/2008	21:20:22	14.33	0.00
3/17/2008	18:20:22	14.33	0.00
3/17/2008	15:20:22	14.33	0.00
3/17/2008	12:20:23	14.33	0.24
3/17/2008	11:49:15	14.29	0.20
3/17/2008	11:29:12	14.25	0.16

Date	Time	Cumulative Precip (in)	Storm total (in)
3/17/2008	11:20:55	14.21	0.12
3/17/2008	11:12:28	14.17	0.08
3/17/2008	11:03:22	14.13	0.04
3/17/2008	9:20:23	14.09	0.00
3/17/2008	6:20:23	14.09	0.00
3/17/2008	3:20:23	14.09	0.00
3/17/2008	0:20:24	14.09	0.00
3/16/2008	21:20:24	14.09	0.00
3/16/2008	18:20:24	14.09	0.00
3/16/2008	15:20:24	14.09	0.00
3/16/2008	12:20:24	14.09	0.00
3/16/2008	9:20:24	14.09	0.00
3/16/2008	6:20:25	14.09	0.00
3/16/2008	3:20:25	14.09	0.00
3/16/2008	0:20:25	14.09	0.00
3/15/2008	21:20:25	14.09	0.00
3/15/2008	18:20:26	14.09	0.00
3/15/2008	15:20:26	14.09	0.00
3/15/2008	12:20:26	14.09	0.00
3/15/2008	9:20:26	14.09	0.00
3/15/2008	6:20:26	14.09	0.00
3/15/2008	3:20:27	14.09	0.00
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