IT'S FLOODING DOWN IN TEXAS

LESSONS LEARNED FROM ~~SIX~~ SEVEN MASS FLOOD EVENTS

2018 National Bridge Preservation Partnership

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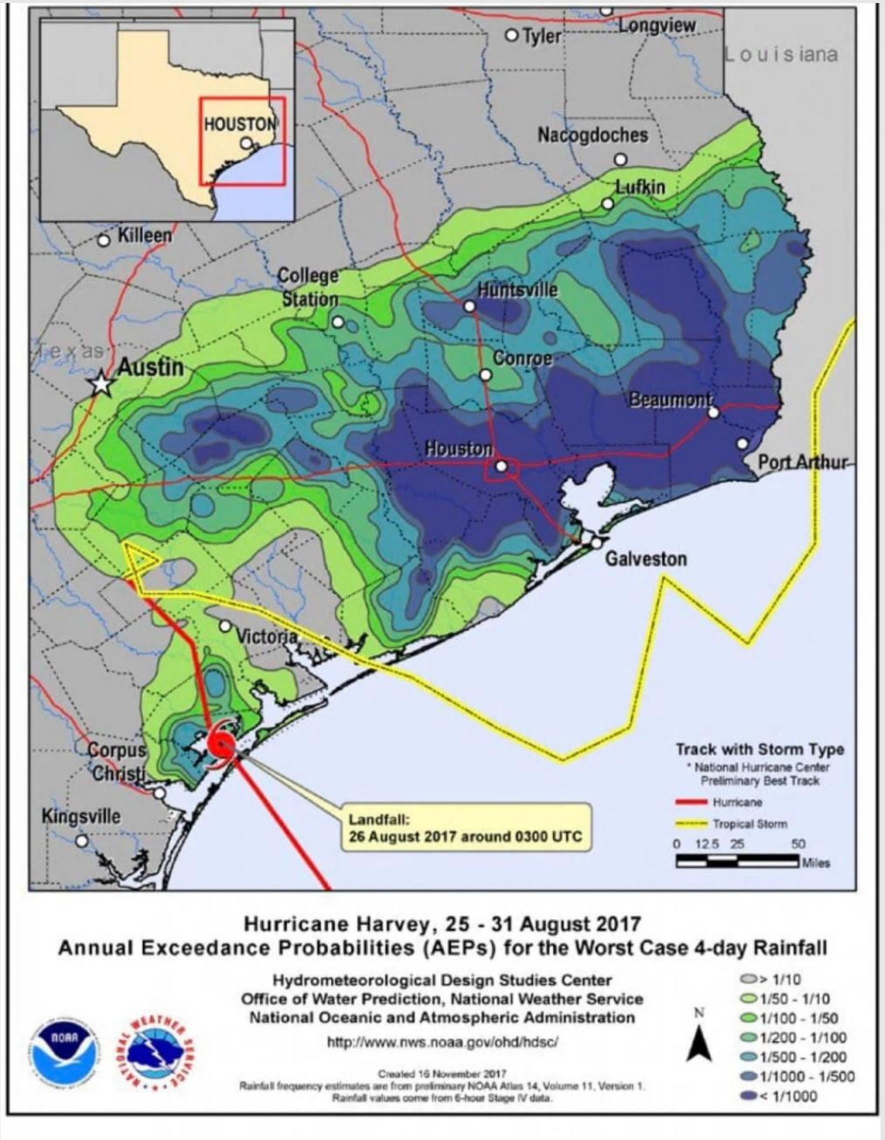
Texas Flooding in 2015 and 2016

1. Memorial Day 2015 in Central Texas
2. Summer 2015 North Texas (Red River)
3. Halloween Flooding 2015 in Central Texas
4. Spring Break (March) 2016 East Texas (Sabine River)
5. Sustained Rain Events April, May, and June 2016 East Texas (especially Houston)
6. June 2016 Central Texas

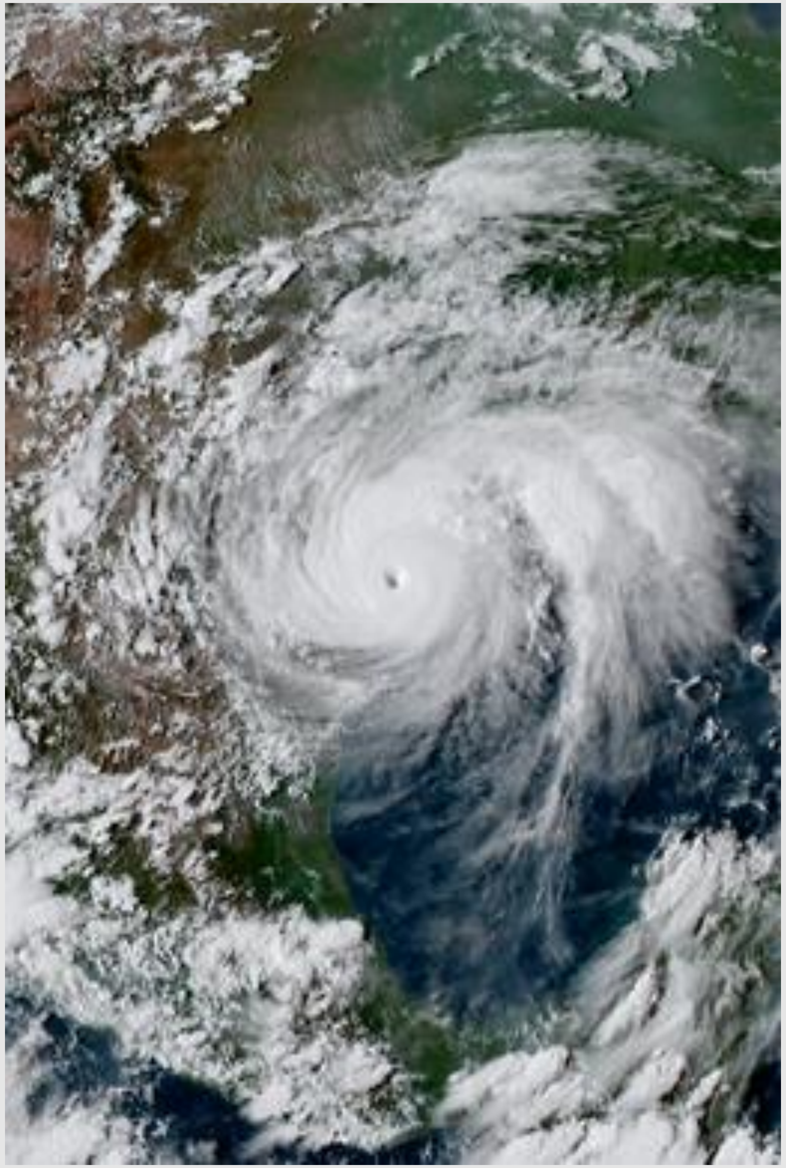
And Then Came Harvey…

- Tropical Storm Allison was previous benchmark for highest rain totals in Texas.
- Hurricane Harvey dwarfed the Allison numbers and set the record for the highest rain total in the Continental United States.
- After making landfall and moving away from Corpus Christi, forward movement slowed and Harvey stalled over Southeast Texas (Houston and Beaumont).



Lessons Learned

- At 2017 SEBPP this presentation focused on ten lessons learned during six mass flood events in 13 months. Those lessons were hugely beneficial during our Harvey response.



Memorial Day 2015

Still intact!

Lesson No. 1 – Setting up a Bridge Command Center

- Establish bridge-specific command center separate from overall Emergency Operations Center.
- Not everyone gets to go in the field. Some knowledgeable personnel, especially geotechnical engineers, must stay behind.
- Ready access to current bridge files.
  - Channel profiles.
  - Inspection reports (to determine whether damage was pre-existing).
  - Design/As-Built plans. This can be problematic for bridges owned by cities and counties.
- Harvey: we staffed both the statewide EOC and ran the bridge EOC, which created several headaches but overall worked very well.

Lesson No. 2 – Don't Get Ahead of Yourself

- Weather events can shift dramatically from predictions.
- Often little to accomplish by responding while event is ongoing.
  - Maintenance personnel must check roadways and bridges, but…
  - not much can be evaluated.
  - Focus on identifying critical structures, especially scour critical bridges.
- Be prepared as soon as water recedes.

Yep, it's flooded

Lesson No. 2 – Don’t Get Ahead of Yourself

- With Harvey we found out this is easier said than done because everyone starts to get panicky if the bridge people aren’t out there doing evaluations

Yep, it’s still flooded

Scour is the Exception – Can't Wait for Those

- Identify scour-critical bridges and evaluate as soon as you can safely do so.
- Evaluating for scour:
  - Weighted tapes, probes, and gauges work very well for rapid assessments.
  - Depth-gauges (we call them shi-flos, which is a fancy word for a fish finder attached to a water ski) are more accurate, especially if there is a fast-moving current.
  - Underwater Imaging/Side-Scan Sonar.

Depth-Gauge (or Shi-Flo, in Texan)

Depth gauges are effective with fast-flowing current.

Lesson No. 3 – Initial Evaluations

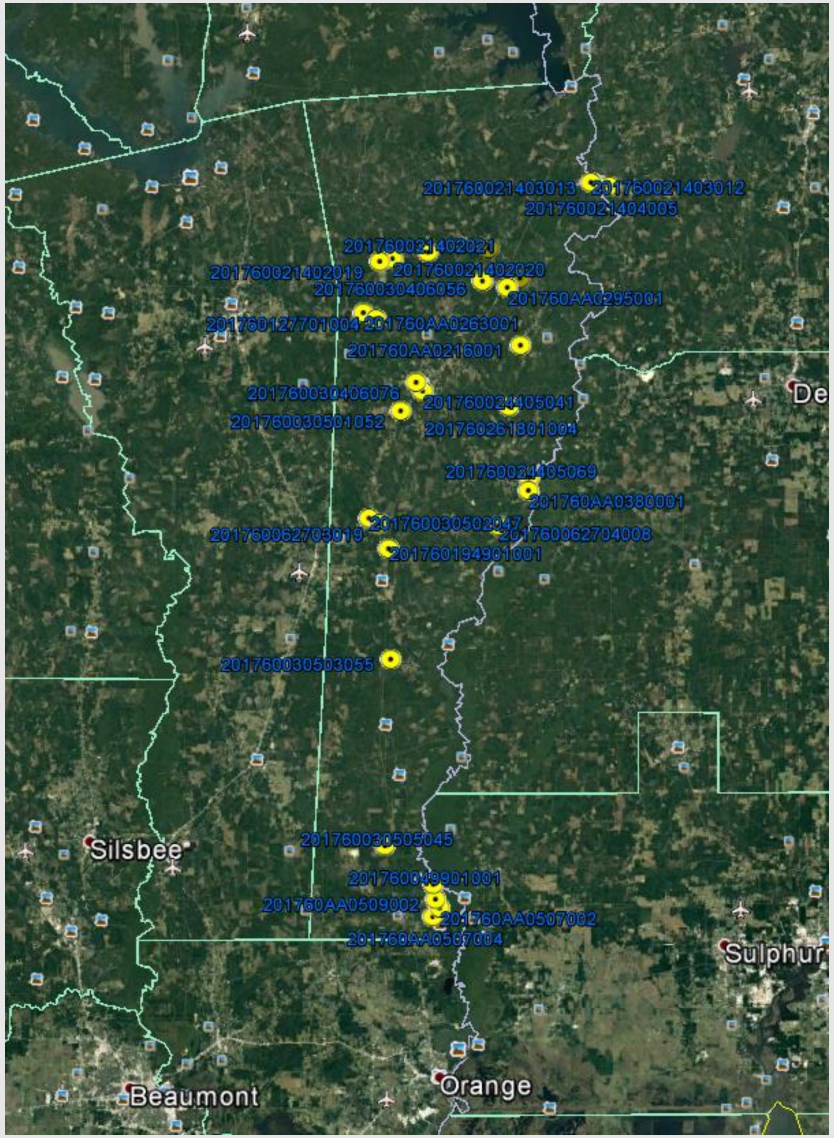
- Vast majority of structures do not sustain damage, even in extreme events.
- Better served to direct initial investigations performed by others (e.g. Maintenance forces).
- Allow bridge specialists to focus on structures where damage is identified.
- This worked great during Harvey, with a couple of exceptions (we'll get to that later).

Lesson No. 4 – Effective Communication

Happy Labor Day 2017!

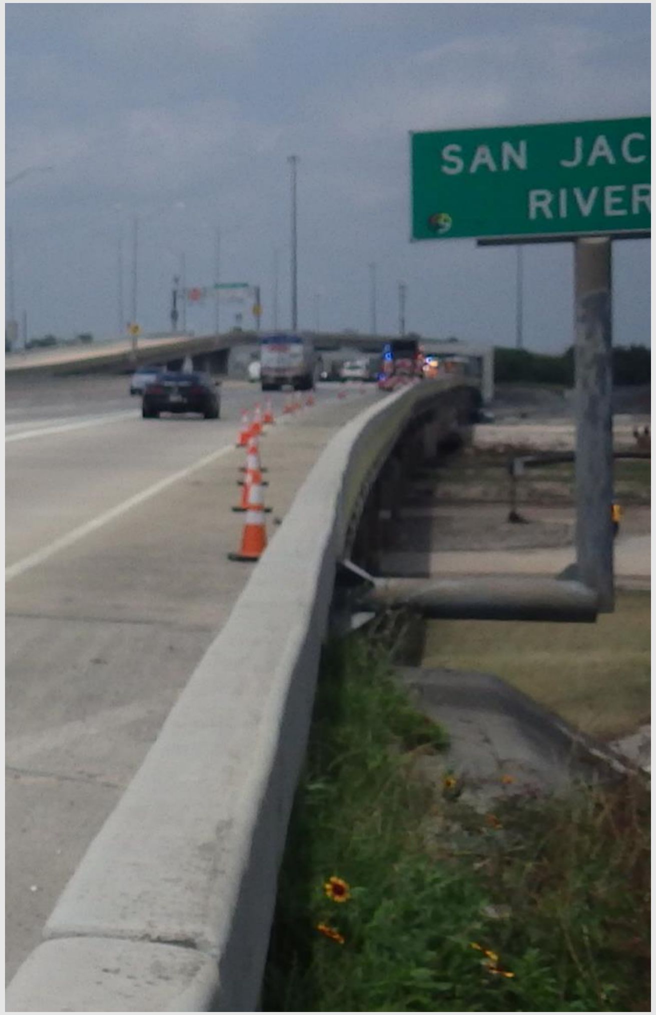
- Field Response
  - Bridge Command Center does the leg work.
  - Have overall leads attend tailgate meetings, briefings, etc.
  - Allow field personnel to remain focused on field evaluations.
- Do not allow others to derail field team efforts! Must be responsive to emergencies, but also stay systematic in overall approach.
- Get out ahead of logistical issues like lodging, fuel, food, and water.

- Generate lists of bridges and place them on a map (e.g. KMZ files imported to GoogleEarth).
- Teams may be covering large geographic areas, avoid bouncing around.
- Worked great during Harvey. Find My Friend app to track team locations via iPhones proved to be very effective.
- Particularly effective when we needed to find the closest team when an emergency was reported.



Lesson No. 4 – Effective Communication

- Traffic Control – striking a good balance.
- Overly elaborate traffic control can take 2+ hours to set up, severely limiting the number of bridges that can be evaluated.
- Inadequate traffic control can lead to unacceptable levels of exposure.
- Typically needed only to measure channel profiles and to identify scour (short duration).
- Having two traffic control teams can vastly increase productivity.
- Communicate intent and duration. Distributed standard procedure during Harvey.



Lesson No. 5 – Standard Procedures

- Prepare Standard Operating Procedures for primary tasks.
- Short and sweet (we aim for one page each).
- Tasks
  - Command Center Responsibilities
  - Querying Data, Generating Maps
  - Initial Bridge Evaluations
  - Setting up Traffic Control
  - Measuring Channel Profile
- This was a homerun during Harvey. Distributed standard procedures for Traffic Control, Initial Evaluations, and In-Depth (Scour) Evaluations. Now trying to get out and communicate procedures during regular meetings instead of during the actual emergency event.

Lesson No. 6 – Establish Statewide Standards

- How to determine bridge criticality and susceptibility to catastrophic damage?
- Over the course of the various flood responses we found that criteria differed significantly from District to District.
- Must avoid overly-conservative criteria. Otherwise it becomes difficult to identify the truly critical structures.
- Establish statewide criteria for categorizing structures as scour critical.
- This was once again a major pain point during Harvey.

Lesson No. 6 – Establish Statewide Standards

	A	B	C	D	E	F	G	H	I	J	K	L	M	N
1	Bridge/ Culvert	BRKEY	DIST	CNTY	" F " Inspection needed due to FLOODING	CTRL	MAINT_SEC	SEC	STRUC	RTE	BRDG_DSCR	FEAT_CROSS	LOCN	BRDG_TYPE_CD
1059	Bridge	121020050801255	12	102	F	0508	19	01	255	IH 10 EB FR	5 Simple Span P/S Concret	GREENS BAYOU	1.0 MI E OF FEDERAL	B
1060	Bridge	121020050801317	12	102	F	0508	09	01	317	IH 10 EB	21 - Span (3 - Continuous S	SAN JACINTO RIVER	IH 10 @ SAN JACINTO	B
1061	Bridge	121020050801457	12	102	F	0508	19	01	457	IH 10 WB	5 Simple Span P/S Concret	GREENS BAYOU	1.0 MI E OF FEDERAL	B
1062	Bridge	121020263301202	12	102	F	2633	09	01	202	FM 526 NB	9 - Simple PS Concrete Gi	GREENS BAYOU	1.5 MI S OF US 90	B
1063	Bridge	121020263301234	12	102	F	2633	09	01	234	FM 526 SB	9 - Simple PS Concrete Gi	GREENS BAYOU	1.5 MI S OF US 90	B
1064	Bridge	121020325603051	12	102	F	3256	09	03	051	BW 8 NB FR	12 - Simple Span P.S. Con	UP RR, CARPENTER	0.20 MI N OF IH 10	B
1065	Bridge	121020325603052	12	102	F	3256	09	03	052	BW 8 SB FR	13 - Simple Span P.S. Con	UP RR, CARPENTER	0.10 MI N OF IH 10	B
1066	Bridge	121020017706081	12	102	F	0177	10	06	081	US 59 SBML	26 - Continuous Span Steel	SAN JACINTO RIVER	1.7 MI N OF FM 1960	B
1067	Bridge	121020017706134	12	102	F	0177	10	06	134	US 59 NBML	26 - Simple Span Prestress	SAN JACINTO RIVER	1.7 MI N OF FM 1960	B
1068	Bridge	121020017706224	12	102	F	0177	10	06	224	US 59 SBFR	3 - Simple Span Prestresse	SAN JACINTO RI REL	1.0 MI N OF FM 1960	B
1069	Bridge	121020017706226	12	102	F	0177	10	06	226	US 59 W CONN	3 - Simple Span Prestresse	SAN JACINTO RIVER	1.0 MI N OF FM 1960	B
1070	Bridge	121020017706230	12	102	F	0177	10	06	230	US 59 NBFR	18 - Simple Span Prestress	SAN JACINTO RIVER	1.7 MI N OF FM 1960	B
1071	Bridge	121020017706231	12	102	F	0177	10	06	231	US 59 HOV	27 - Span (8 - Continuous S	SAN JACINTO RVR &	1.7 MI N OF FM 1960	B
1072	Bridge	121020017706232	12	102	F	0177	10	06	232	US 59 SBFR	21 - Simple Span Prestress	SAN JACINTO RIVER	1.7 MI N OF FM 1960	B
1073	Bridge	121020017706233	12	102	F	0177	10	06	233	US 59 NBFR	3 - Simple Span Prestresse	SAN JACINTO RI REL	1.0 MI N OF FM 1960	B
1074	Bridge	121020017706236	12	102	F	0177	10	06	236	US 59 NB OFF-RP	3 - Simple Span Prestresse	SAN JACINTO RI REL	1.0 MI N OF FM 1960	B
1075	Bridge	121020072003073	12	102	F	0720	10	03	073	SH 249 SBFR	Three Simple Span Prestres	WILLOW CREEK	2.10 MI S OF FM 2920	B
1076	Bridge	121020072003074	12	102	F	0720	10	03	074	SH 249 NBFR	Three Simple Span Prestres	WILLOW CREEK	2.10 MI S OF FM 2920	B
1077	Bridge	121020100501005	12	102	F	1005	10	01	005	FM 525	3 - Simple Span Prestresse	GREENS BAYOU	3.5 MI E OF IH 45	B
1078	Bridge	121020294102001	12	102	F	2941	10	02	001	FM 2920	Six Simple Spans Reinforce	WILLOW CREEK	2.2 MI SE OF FM 2978	B
1079	Bridge	121020325602006	12	102	F	3256	10	02	006	BW 8 EBFR	7 - Simple Span Prestresse	GREENS BAYOU	1 MI W OF JFK BLVD	B
1080	Bridge	121020325602007	12	102	F	3256	10	02	007	BW 8 WBFR	7 - Simple Span Prestresse	GREENS BAYOU	1 MI N OF JFK BLVD	B
1081	Bridge	121020325602082	12	102	F	3256	10	02	082	BW 8 WB FR	3 Simple Span P.S. Concre	GARNERS BAYOU	3.78 MI E OF US 59	B
1082	Bridge	121020325602083	12	102	F	3256	10	02	083	BW 8 EB FR	3 - Simple Span P.S. Conc	GARNERS BAYOU	3.75 MI E OF US 59	B
1083	Bridge	121020325602099	12	102	F	3256	10	02	099	BW 8 WBFR	5 - Simple Span Prestresse	GREENS BAYOU	1.5 MI E OF ANTOINE	B
1084	Bridge	121020325602100	12	102	F	3256	10	02	100	BW 8 EBFR	5 - Simple Span Prestresse	GREENS BAYOU	1.5 MI E OF ANTOINE	B
1085	Bridge	121020325602101	12	102	F	3256	10	02	101	BW 8 EBFR	5 - Simple Span Prestresse	GREENS BAYOU	1.9 MI E OF ANTOINE	B
1086	Bridge	121020325602102	12	102	F	3256	10	02	102	BW 8 WBFR	5 - Simple Span Prestresse	GREENS BAYOU	1.9 MI E OF ANTOINE	B
1087	Bridge	121020325602105	12	102	F	3256	10	02	105	BW 8 WBML	3 - Simple Span Prestresse	GREENS BAYOU	.5 MI E OF ALDINE W	B
1088	Bridge	121020325602106	12	102	F	3256	10	02	106	BW 8 EBML	3 - Simple Span Prestresse	GREENS BAYOU	.5 MI E OF ALDINE W	B
1089	Bridge	121700011004118	12	170	f	0110	25	04	118	IH 45 SBFR	8 Span (3 Cont. Steel Girde	SPRING CR	AT HARRIS C/L	B
1090	Bridge	121700011004119	12	170	f	0110	25	04	119	IH 45 SBML	8 Span (3 Cont. Steel Girde	SPRING CR	AT HARRIS C/L	B
1091	Bridge	121700011004120	12	170	f	0110	25	04	120	IH 45 NBML	8 Span (3 Cont. Steel Girde	SPRING CR	AT HARRIS C/L	B
1092	Bridge	121700011004121	12	170	f	0110	25	04	121	IH 45 NBFR	8 Span (3 Cont. Steel Girde	SPRING CR	AT HARRIS C/L	B
1093	Bridge	121700011004122	12	170	f	0110	25	04	122	IH 45 SBFR	Three Simple Span Prestres	SPRING CR REL	0.2 MI N OF HARRIS C	B
1094	Bridge	121700011004165	12	170	f	0110	25	04	165	IH 45 SBFR	11- Simple Span P. S. Con	W FK SAN JAC RI N	0.90 MI N OF FM 1488	B
1095	Bridge	121700011004166	12	170	f	0110	25	04	166	IH 45 SBFR	3 - Cont. Span Steel Girder	W FK SAN JACINTO	0.65 MI N OF FM 1488	B
1096	Bridge	121700011004167	12	170	f	0110	25	04	167	IH 45 SBFR	Four Simple Span Prestres	W FK SAN JACINTO	0.20 MI N OF FM 1488	B
1097	Bridge	121700011004168	12	170	f	0110	25	04	168	IH 45 NBFR	11- Simple Span P. S. Con	W FK SAN JAC RI N	0.90 MI N OF FM 1488	B
1098	Bridge	121700011004169	12	170	f	0110	25	04	169	IH 45 NBFR	3- Cont. Span Steel Girder	W FK SAN JACINTO	0.65 MI N OF FM 1488	B
1099	Bridge	121700011004170	12	170	f	0110	25	04	170	IH 45 NBFR	Four Simple Span Prestres	W FK SAN JACINTO	0.20 MI N OF FM 1488	B
1100	Bridge	121700017705119	12	170	f	0177	05	05	119	CREEKWOOD LN	3 Simple Span Reinforced (	PEACH CREEK	1.20 MI N OF SH 242	B
1101	Bridge	121700072002033	12	170	f	0720	05	02	033	SH 249 SB	26 Simple Span Reinforced	SPRING CREEK	4.35 MI SE OF FM 149	B
1102	Bridge	121700072002042	12	170	f	0720	05	02	042	FM 149	4 -Simple Span Reinforced	LAKE CREEK	7.50 MI S OF SH 105	B
1103	Bridge	121700106201011	12	170	f	1062	05	01	011	FM 1485	7 Simple Span Reinforced (	E FORK SAN JACINT	5.4 MI E OF LP 494	B
1104	Bridge	121700141603020	12	170	f	1416	05	03	020	FM 1486	Three Simple Span Prestres	MILL CREEK	1.50 MI N OF FM 1774	B
1105	Bridge	121700305002001	12	170	f	3050	05	02	001	FM 2978	24 -Simple Span Reinforced	SPRING CREEK	6.80 MI S OF FM 1488	B

1,102 Bridges!

To Close or Not to Close?

Oh, the irony! I showed this photo at SEBPP as an example of a bridge we thought had scoured in 2016 but didn't. During Harvey it turned out to be the single worst (and most expensive) scour issue we experienced.

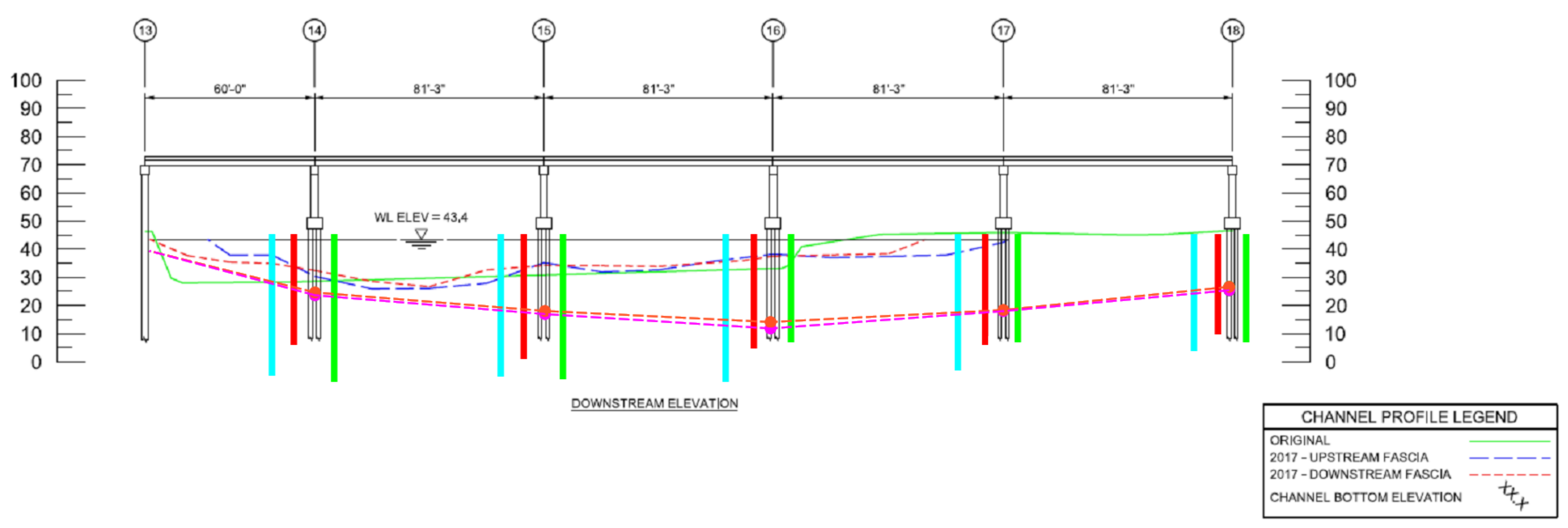
Harvey Flooding in Houston

Truss from previous slide.

Channel Migration Due to Debris Build-up

Six bridges with varying span lengths and bent locations created a major debris catch.

Channel Migration Due to Debris Build-up



As a result of the debris, the channel shifted nearly 100 feet to the north and caused approximately 20 feet of scour at several approach bents. Four spans are currently being replaced.

Lesson No. 7 – Be Willing to Make Difficult Decisions

- Cannot afford to be overly conservative in assessing damage.
- Closing bridges, especially during emergencies, can have serious ramifications to traveling public and emergency responders.
- Close when appropriate, but don't play it too safe. This is a difficult thing for many engineers.

- Ensure that scour evaluations are performed at the appropriate time.
- The second scour event, when water recedes, can be more severe than the initial event. Frequently a second evaluation is needed.
- Oftentimes unable to get divers in the water.
- Use depth-detection devices.
- Expand use of underwater imaging/side scan sonar (many, many thanks to Infrastructure Engineers for their help in Texas).

Pier 10 – North Face

Lesson No. 9 – Bridge Approaches REALLY Don't Like Water

- As water levels rise and debris clogs hydraulic openings, water moves to the bridge approaches.
- For approaches built well out of the main channels there are frequently no effective erosion controls in place.

Lesson No. 9 – Bridge Approaches REALLY Don't Like Water

Erosion at Bridge Ends

But the Bridge Survived!

That's an abutment, not a bent.

Two Events – Water Arrives and Water Leaves

Before and after shots. The first photo was taken Saturday, 9/3/17, and the second on Sunday, 9/4/17. Damage doesn't occur only when the water comes in; frequently scour and erosion can be significant as water levels drop.

Erosion

It looks bad but there is sufficient remaining embedment. More often it becomes an unbraced length issue rather than an axial capacity problem.

Lesson No. 10 – Damage Isn't Always Obvious

- Look under all bridges along flooded waterways – damage (sometimes even severe damage) isn't always obvious from the roadway.

Debris

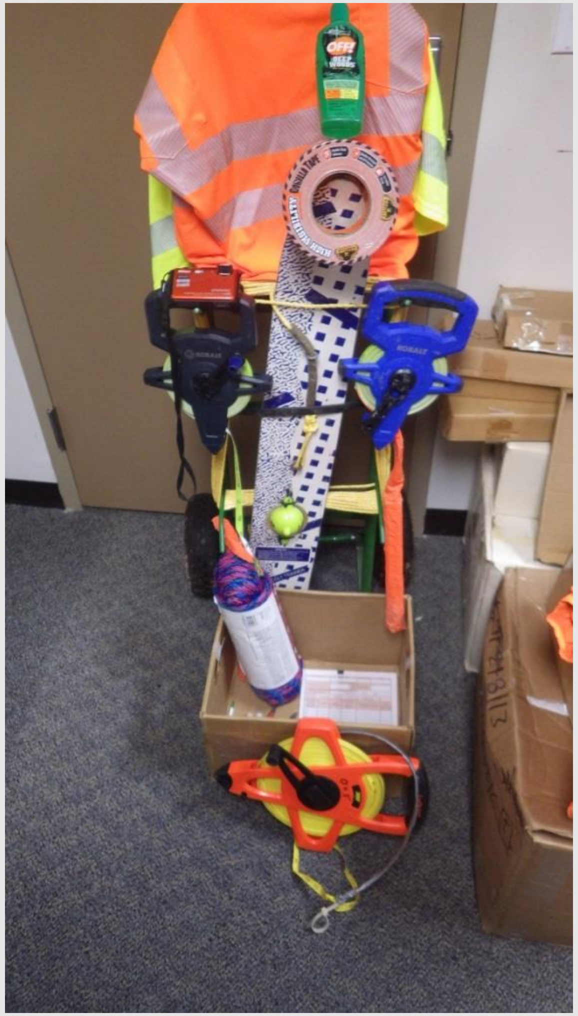
- Debris is a major problem, regardless of whether there is a fast or slow rise in the water.
- Particularly during Harvey, we observed bridges where the hydraulic openings were so clogged with debris that substantial channel migration occurred.
- Fast moving debris can cause damage to bridge substructure elements.

Debris

- Particularly problematic where older bridges with short spans have lots of columns and other superstructure elements to collect debris.
- What NOT to do? Seems obvious but we've seen it happen:
  - DO NOT try to set the debris on fire.
  - DO NOT pick up debris from one side of the bridge and place it in the waterway on the other side of the bridge.

Equipment and Tools

- Keep Equipment Readily Available.
  - Depth-Detection Devices
  - Weighted Tapes
  - GPS-Enabled Cameras
  - Safety Equipment and Other Standard Tools
- Ensure that out of date equipment is replaced.
- Make sure there are sufficient numbers of personnel that know how to use the equipment.



Harvey Go-kits with all the necessary equipment.

Design Considerations

- Shear keys = Good.
  - TxDOT is using them on essentially any waterway where the superstructure could be flooded.
- Shear Walls = Not Always So Good.
  - Effective as long as flow is parallel to walls but that can change drastically over the life of a bridge or even during a single event. They can become debris catchers.
- Tie beams = Usually Good.
  - Tie beams have been effective in limiting distress and don’t catch nearly as much debris as the walls.
- Channels move over the life of a bridge. Consider whether deep foundations should be designed at approach spans that could become channel spans.

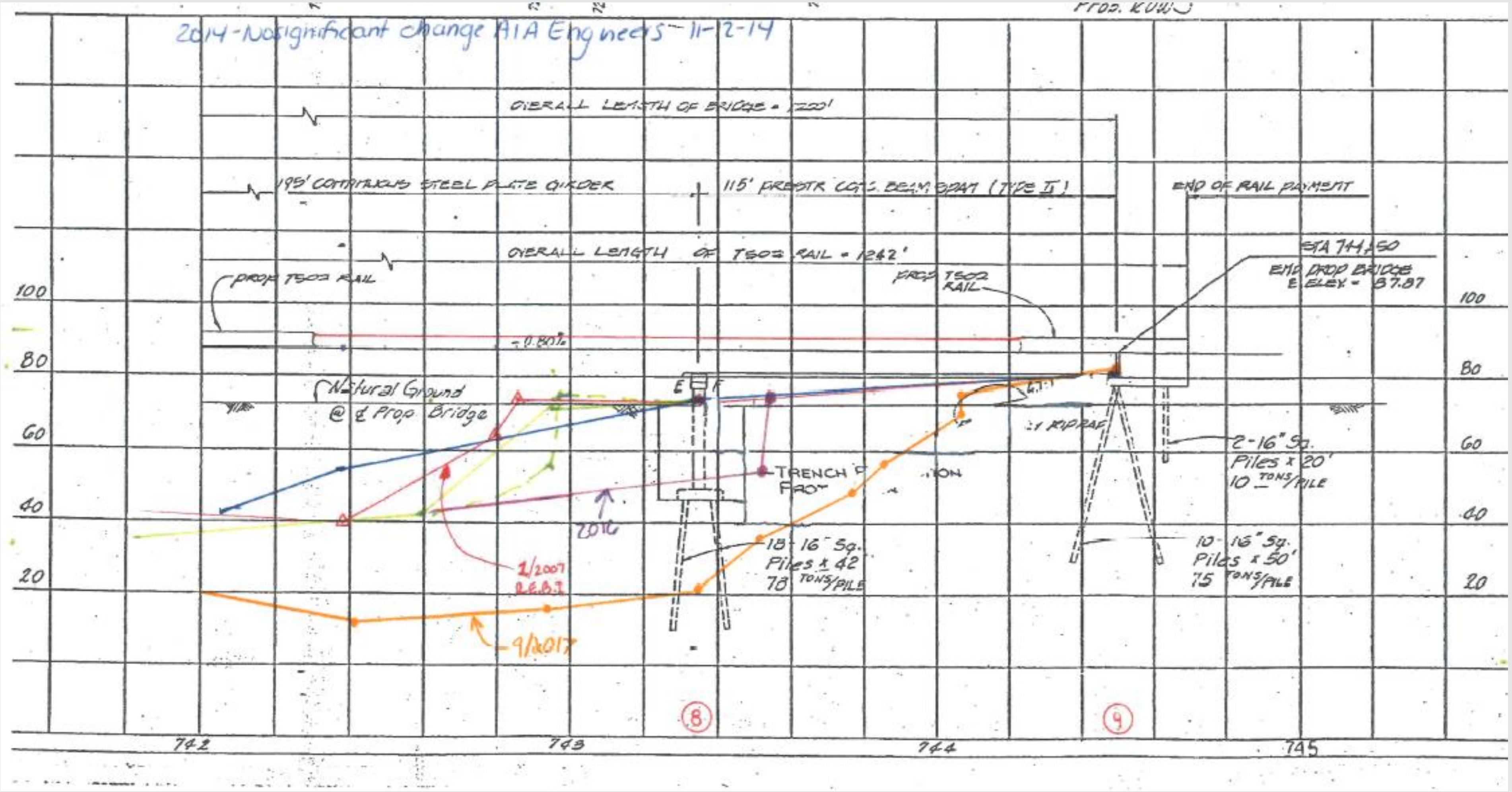
Memorial Day 2015 Flash Flooding

Shear walls typically work very well unless the channel location/direction changes and they become debris catchers

Deep Foundations at Approach Spans

Colorado River channel shifted 40 feet in this location.

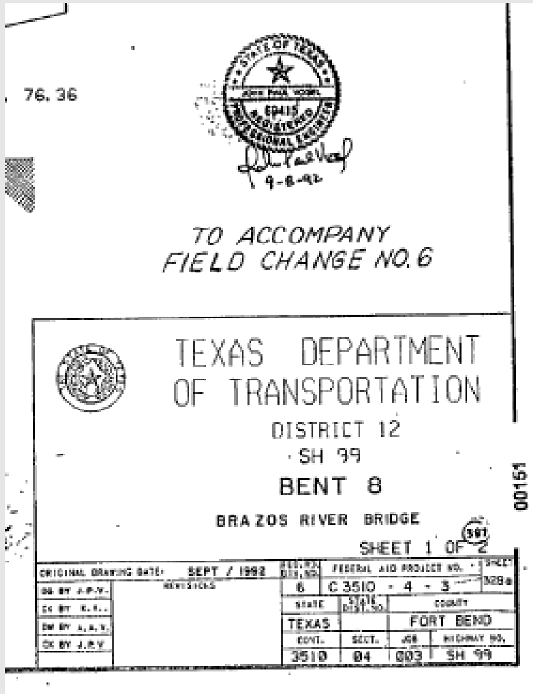
Deep Foundations at Approach Spans

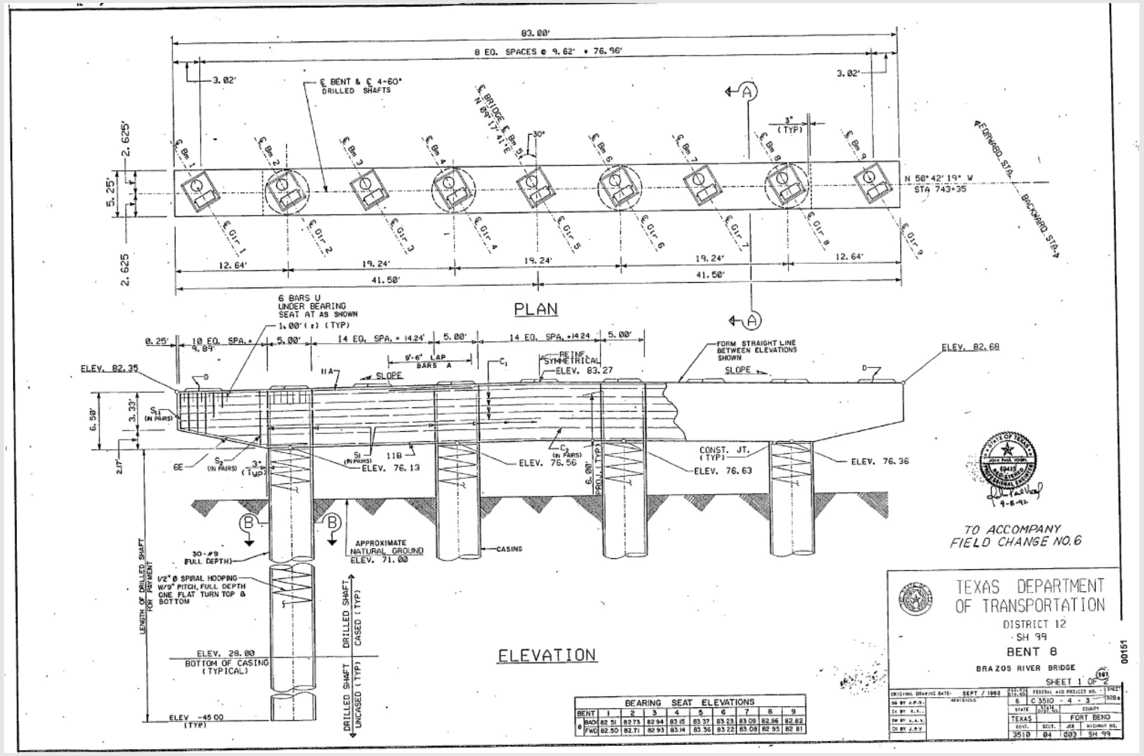


According to channel profile and original plans, the bridge needed to be closed.

Deep Foundations at Approach Spans

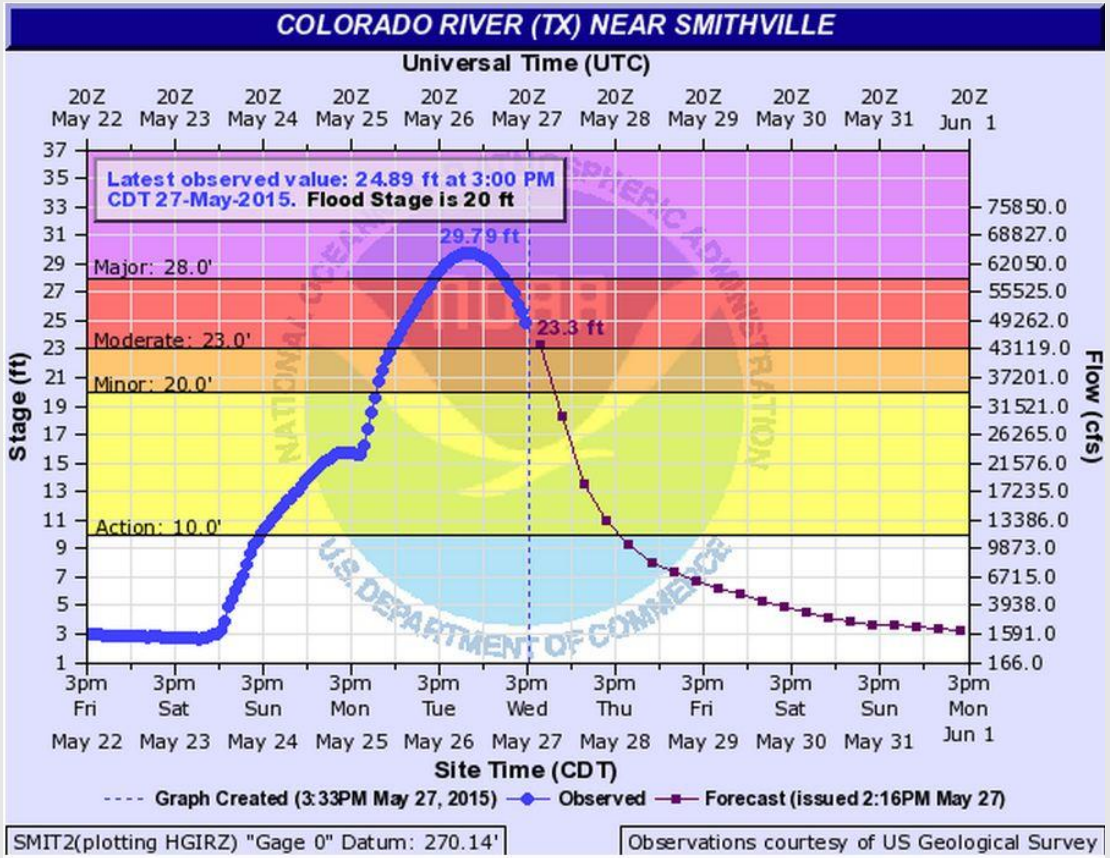
- After noting differences between site conditions and plans, we found additional documentation on significant Field Changes that had not been incorporated into the As-Built Plans.
- Turns out they had considered this exact scenario (channel migration) and made a change to include additional deep foundation elements after construction of the bridge commenced.





Hydrographs

- Hydrographs are a powerful and useful tool.
- TxDOT is currently working with the National Weather Service and USGS to vastly expand the number of gages installed on bridges over waterways that are susceptible to flooding.



Additional Lessons

- Geography matters.
  - In the rocky and steep hill country (e.g. Central Texas), the water levels rise and fall quickly. Scour is often not significant.
  - Along the coastal, flat areas (e.g. Southeast Texas) the rise and fall of the water is more gradual and takes a longer period of time. Scour and bank erosion are typically more significant in this region.
  - Either way, debris can be a major problem.
- When feasible, work with maintenance crews to develop solutions that can be implemented in-house.
- Load testing is a great tool for unknown foundations or when analysis shows inadequate capacity.

Memorial Day 2015 Flash Flooding

The Blanco River rose so rapidly in 2015 that the bridges were overtopped quickly and then water dropped quickly. There was not sufficient time for scour to develop in the clay soils.

Truss Bridge at Sabine River (Repeat Offender)

Truss Bridge at Sabine River

No messing around this time!

Everybody needs one of these guys, what my boss called a "courageous engineer" during Harvey. He made difficult calls on dozens of bridges that sustained scour.

Load Test

Simplified Scour Repair

Simplified Scour Repair Performed In-House

The Good News

- Our bridges stood up extremely well to the flood events, particularly Harvey.
- Current design and construction practices, and the National Bridge Inspection Program, are doing their job.
- It's important to help control the message. During Harvey we had multiple reports of catastrophic bridge collapses being reported by various agencies and news outlets that were not even remotely accurate.
- Also important to help minimize the hysteria. Responding during these events is extremely stressful and tiring. It is critical to maintain a level-headed approach, stay focused on the systematic tasks at hand, and work to alleviate the fears of others.

The Bad News

- The instances of significant scour are rare and isolated. I know, that sounds like good news.
- There is little rhyme or reason to when or where significant scour or erosion events will occur. It isn't along the same waterways, in the same geographic regions, or any other common denominator.
- At the end of the day, we have to accept that water does funny things. It's unpredictable, and so is scour and erosion.

Our Conclusion?

- Post-Harvey, we needed to put eyes on every single on-system water crossing in the Houston and Beaumont regions (over 4,000 bridges).
- Significant damage occurred at only a handful of bridges, but due to the random nature of the scour and erosion the widespread evaluation was necessary.
- Almost every bridge that experienced significant scour or erosion was not on our list of "at risk" structures.

QUESTIONS?

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