25 years of fixing bridges on gravel mined rivers in California

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ABSTRACT: The degradation caused by instream and off channel gravel mining and its resultant impact on bridges is investigated. Three case studies in California are utilized to illustrate the cost of fixing bridges impacted by channel bed degradation. Revisions to California regulations are suggested to increase awareness and decrease taxpayer costs.

1 INTRODUCTION

With the upturn in the California economy, there is an increased demand for sand and gravel (Figure 1) used in construction activities. California is the nation's leading producer of construction aggregates using 240 million tons on average[1] The California Department of Conservation (DOC) estimates that 20 percent of construction aggregate comes from instream sources (Avila, 1998). In 1996, 289 instream operations produced 22.8 million tons of sand and gravel valued at $114 million (DOC, 1998). The average annual bedload sediment yield for all the rivers in California is only about 13 million metric tons (Kondolf, 1995). Thus, instream operators extract almost twice the sediment yield in an average year.

Figure 1: Gravel sorting operation (photo by author)

Gravel extraction is regulated in California by the Surface Mining and Reclamation Act of 1975. The California Department of Transportation (Caltrans) had section 3710 added which mandated that Caltrans be given an opportunity to comment on any operations within 1 mile upstream or downstream of a state bridge. Comment letters from Caltrans often resulted in revisions to mining operation permits which decreased the impact to infrastructure. In 1997, Caltrans received a letter from the Federal Highway Administration (FHWA) noting that of the 17 bridge failures in the 1995 storms, "several failures could be attributed to aggregate mining" [2]. The letter prompted some local agencies to attempt to curtail instream operations in their County. San Benito County provides such an example and described below.

2 CASE STUDY #1 SAN BENITO RIVER IN SAN BENITO COUNTY

Many California counties document the 1950's as the beginning of large scale instream gravel extractions within the active channel. These larger scale operations began at approximately the same time as the construction of the Interstate Highway System. The San Benito River provided aggregate for the construction of highways and also had an annual gravel extraction rate since 1952 (87,000 m3 to 132,000 m3) which far exceeded the estimated annual replenishment of sediment (18,000 m3 to

[1] http://www.calcima.org/html/fast_facts.html accessed June 2, 2016.

[2] http:// https://trid.trb.org/view.aspx?id=481724 accessed June 10, 2016.

45,000 m3). The degradation downstream and head cutting upstream as seen in Figure 2.

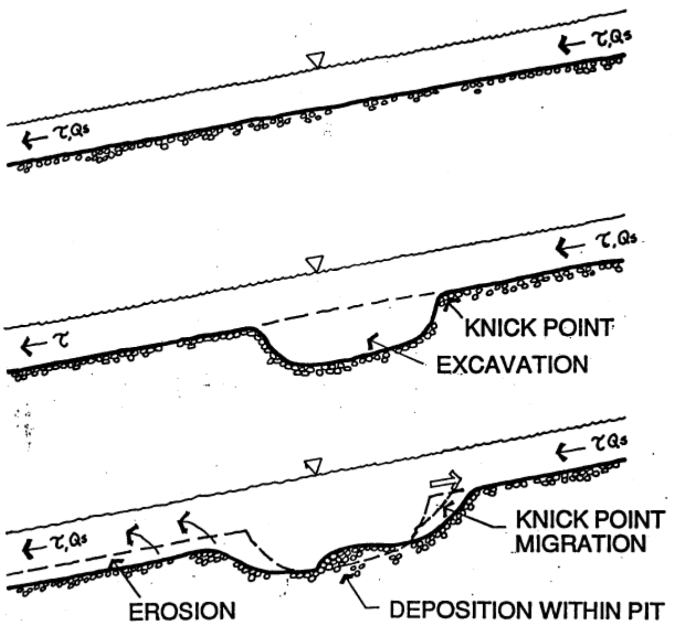


Figure 2: Impact of instream gravel mining (Kondolf, 1993)

Cumulative excavations upstream and downstream of the Union Road Bridge over the San Benito River caused over 3 meters of degradation between 1959 and 2004. This degradation exposed the footings and piles of the bridge as shown in Figure 3 and caused the bridge to be closed to traffic in 1995 until scour countermeasures could be installed at an equivalent 2016 cost of $950,000. The Union Road Bridge is constructed of 4 piers founded on 8 meter long “raymond step taper cans” pile foundation with a 0.6 meter pier cap between the piles and the pier wall as shown in Figure 3. These pile caps were buried approximately 0.6 meters deep when the bridge was originally constructed. If the foundations had been buried more, it would have required very expensive excavation to first drive the piles, then form the pile cap and finally construct the pier wall. CISS pile dot not require the construction a pile cap and thus no need for deep and expensive excavation and are ideal for bridge construction in historically gravel mined channels. The bridge is currently scheduled for replacement with very deep Cast in Steel Shell (CISS) piles to allow for potential future degradation at the bridge at a cost of $21M.

The 1947 aerial photograph shows the old roadway alignment with the former bridge which was a truss structure founded on large caissons (Figure 4). The truss was removed when the new bridge was constructed in 1959 but the old piers were not removed from the river and can be seen as late as 1995. Gravel mining near the bridge began between 1947 and the next available photograph in 1960. The gravel processing plant can be seen north-west of the bridge. The 1974 picture documents an excavation estimated to be 2-3 meters deep 15 to 30 meters upstream of the bridge.

Figure 3: Looking downstream at the exposed footings and piles of the Union Cienega Road Bridge in 1995 (photo by author)

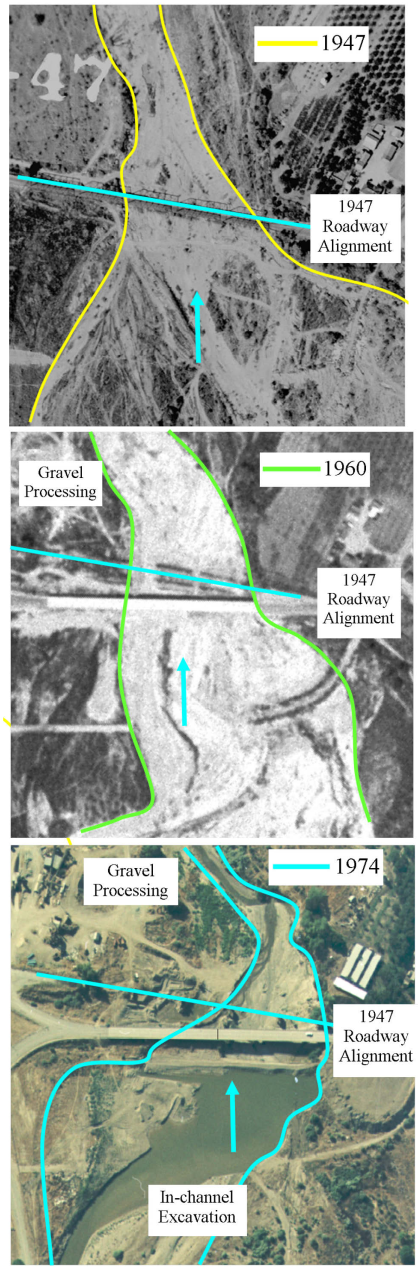


Figure 4: Channel changes over time on the San Benito River, California

As noted above, when gravel is extracted from active channels, it can cause channel bed degradation. Gravel extraction from "off channel" floodplain pits, however, can also cause channel bed degradation. This type of degradation occurs when the active channel migrates into these pits and "captures" them by making them part of the river. Although the Corotto and Tibbetts Pits on the San Benito River were both anticipated to be "off-channel pits", the setback of the Corotto Pit was breached (east bank) and Tibbetts Pit eroded as a result of 1998 storm events. In 2003, the operator amended their Reclamation Plan for these pits in order to make these "off channel pits" part of the river. The impact of such a plan has not been fully evaluated by San Benito County.

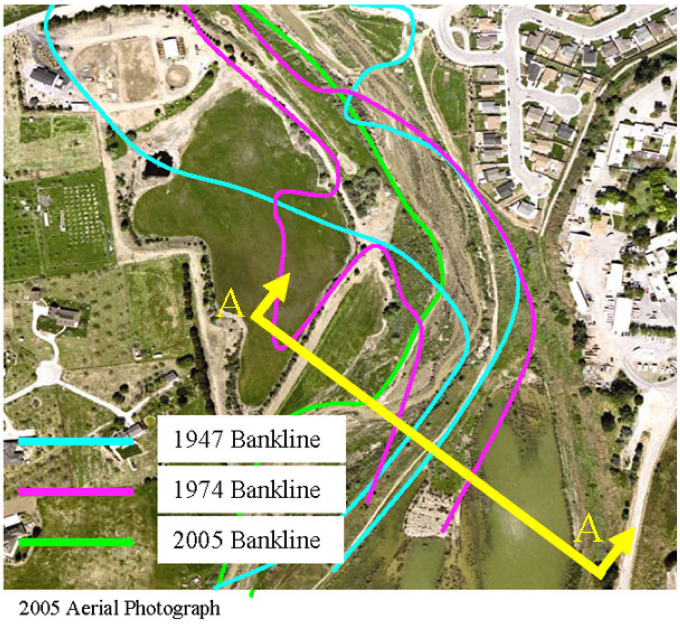


Figure 5. Bankline analysis near the Hospital Road Bridge from 1947, 1974 and 2005 aerial photographs.

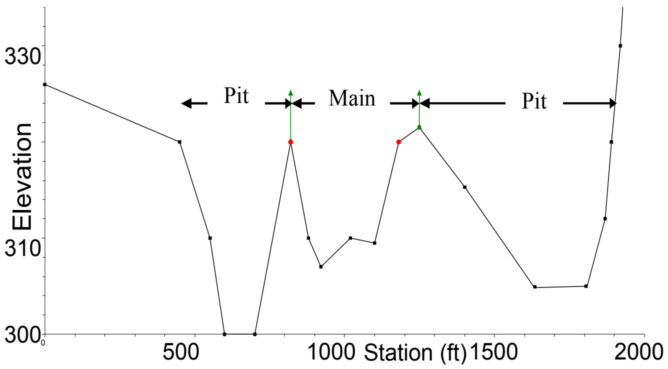


Figure 6: Section AA above which depicts a "perched channel" situated between a reclaimed gravel pit (McClatchy) and soon to be reclaimed pit (Corrotto).

3 CASE STUDY #2 RUSSIAN RIVER IN SONOMA COUNTY

Aggregate companies began mining the Russian River in the 1940s when a freight train ran along the river. In some years, during the peak of gravel mining activities in the 1950s, 1960s and 1970s, one million tons of gravel was taken out of the river. Furthermore, between 1980 and 1995, 42 million tons of gravel were removed from the Russian River (Fimrite, 2010).

As a result of increased awareness of the impacts of instream operations on infrastructure, many operations moved off-stream, either by choice or as mandated by local policies. In 1981, Sonoma County implemented their Aggregate Resources Management (ARM) Plan, one of the first plans in California (Sonoma, 1981). The ARM Plan was supposed to phase out in-channel operations and move these operations to hard rock quarries. Instead, the County opened the terraces to deep-pit gravel mining. In 1990, a Grand Jury Report curtailed deep-pit mining until the adoption of a new ARM Plan in 1994 (Griffin, 1998). The Route 101 Bridge over the Russian River was classified as Scour Critical in 1991. The Russian River thalweg had dropped more than 5 meters since the bridge was constructed in 1959 exposing the bridge foundations (footings and steel "H" piles). The bridge was replaced in 1999 at a cost of $14M (2016 dollars). The 1994 ARM plan proposed phasing out all terrace mining by 2004 (Dugan, 2007). Although instream gravel mining has been virtually eliminated in the middle reach of the Russian River. In 2012, however, Syar Industries was granted a use permit to remove up to 350,000 tons of gravel a year for 15 years in the Alexander Valley Reach (near the Alexander Valley Road Bridge). It took Syar Industries four years of permitting and an additional two years of litigation to obtain the permission. No instream mining had occurred in the Alexander Valley since 2001 (Robertson, 2012).

These instream and floodplain pits have undermined the foundations of several bridges crossing the Russian River and its tributaries. The Alexander Valley Road Bridge (also known as the Jimtown Bridge), in the upper reaches of the Russian River in Sonoma County, provides an example of the impact of channel bed degradation and lateral channel migration The bridge is located just downstream from a designated instream mining area. As shown in Figure 7, the channel has only degraded 0.5 meters since the bridge was constructed in 1949, but it has widened and shifted from the northeast to the southwest side of the river. Because pier 2 (the southwesterly pier) was constructed over 3 meters above piers 3 through 5, this lateral shift has exposed the entire pier and up to 2 meters of pile foundations, rendering the bridge vulnerable to scour and seismic forces. The resumption of gravel operations in the

Alexander Valley Reach may further accelerate this degradation.

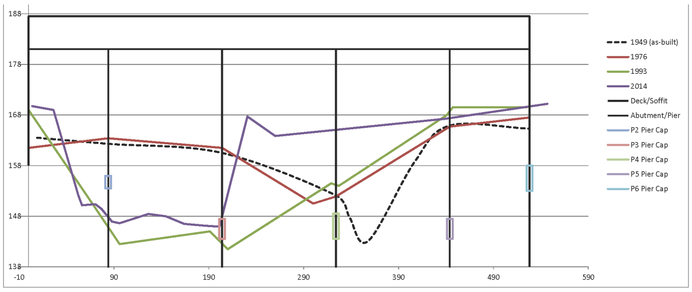


Figure 7: Channel Sections taken over time at the upstream face of the existing Alexander Valley Road bridge

A scour and seismic retrofit analysis of the bridge was commissioned to determine the most cost-effective short term countermeasure that will ensure the bridge stability under flood and earthquake events and protect the safety of the traveling public.

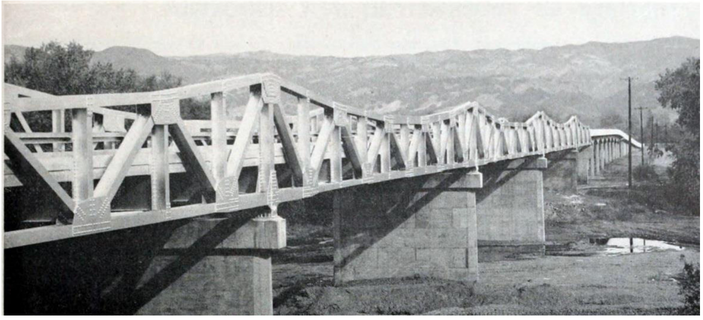


Figure 8: Circa 1949 Bridge looking upstream at the downstream face of the Alexander Valley Road bridge

Figure 9: Existing bridge pier looking upstream at the downstream face of the Alexander Valley Road bridge depicting lateral channel migration

Figure 10: Pier 2 footing of the Alexander Valley Road Bridge with author

Often when the channel degrades significantly, structural countermeasures are required at the bridge. Hydraulic countermeasures, such as placing armoring around the pier, do not mitigate the exposure of the pier or the increased vulnerability of the bridge to seismic forces associated with the exposed footings and undermined piles. Five structural countermeasure alternatives were considered for the Alexander Valley Road Bridge as outlined in Table 1. The recommended alternative is Alternative 2, construction of an outrigger or superbent. The Crocker Road Bridge upstream of the Alexander Valley Road Bridge has already had a similar countermeasure installed as seen in Figure 11. The structural integrity of the bridge has been restored while the aesthetics are up to debate.

Table 1: Bridge Scour Countermeasure Alternatives with associated cost (Quincy, 2015)

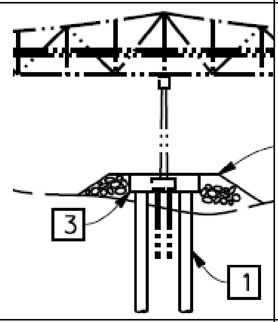
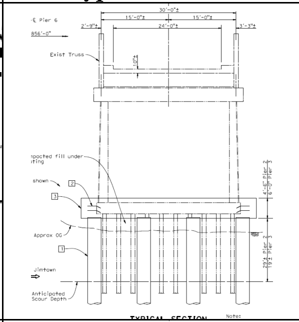
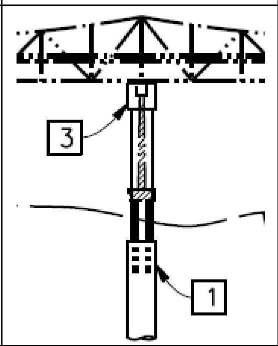
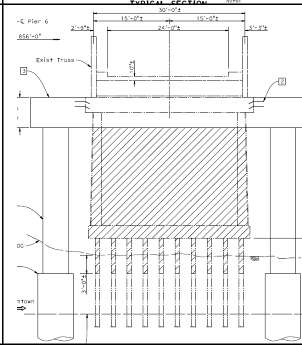
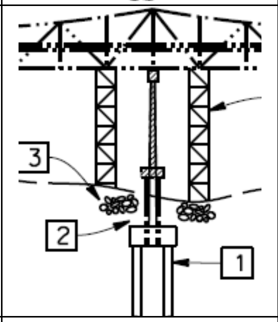
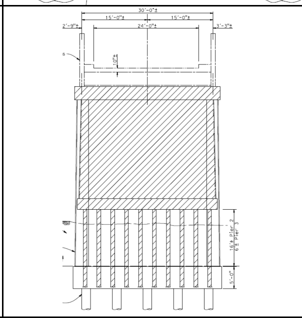
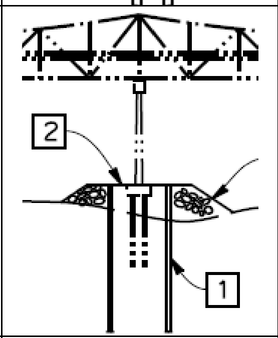
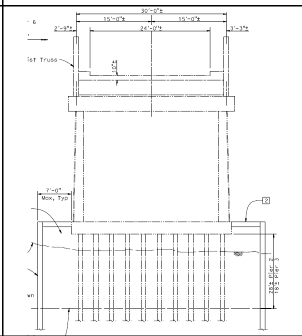
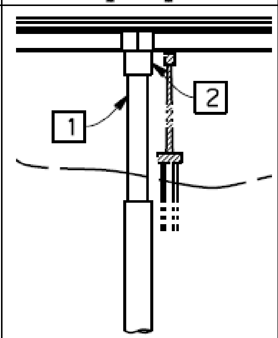
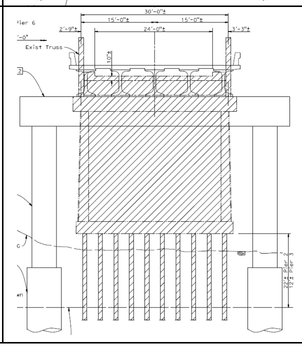
Alternative	Elevation	Typical Section	Cost
1: **Super Footing:** The footing of the bridge is retrofit with an enlarged pile cap and 0.75 meter cast-in-steel-shell (CISS) piles. The local pier scour at the bridge will increase dramatically due to the large obstruction to flow (pier footing) in the flow field.			Pier 2: $490K Pier 3: $550K RSP @A1 & P4: $38K **Total Cost: $1,078,000**
2: **Super Bent**: Replace the existing pier 2 and pier 3 footings with 1.5 meter outrigger bents or “super bents”. The existing pier would be removed once the outrigger bent was completed.			Pier 2: $730K Pier 3: $730K RSP @A1 & P4: $38K **Total Cost: $1,498,000** Fix Piers 2-5: $2,939,000
3: **Replace and Lower Footing**: Remove and replace Piers 2 and 3. Unlike Alternative 1 above, the footing would be removed and replaced at a lower elevation so it would not affect the flow field.			Pier 2: $860K Pier 3: $780K RSP @A1 & P4: $38K **Total Cost: $1,678,000**
4: **Sheet Piles**: Sheet pile coffer dams could be constructed from the top of the footings to below the anticipated scour depth. Similar to Alternative 1, these sheet piles would create a significant obstruction to flow that would dramatically increase the local pier scour.			Pier 2: $540K Pier 3: $530K RSP @A1 & P4: $38K **Total Cost: $1,108,000**
5: **Replace Bridge**: Replacing the truss portion of the existing bridge with superbents similar to Alternative 2 would fix the bridge scour and seismic vulnerability.			**Total Cost: $6,640,000**

Figure 11: Crocker Road Bridge following outrigger bent construction (photo from Sonoma County)

4 CASE STUDY #3 TUOLUMNE RIVER IN STANISLAUS COUNTY

As described above, Sonoma County represents one of the Counties where the citizenry is that is most aware of the impact of gravel mining on infrastructure and environmental resources. Conversely, Stanislaus County in the Central Valley of California has almost no analysis of the impact of the gravel mining operations on the Tuolumne River. The California Department of Conservation includes a graphical database of all of the gravel operations in California. This data collection effort came about primarily as a result of Assembly Bill 3098 which was passed in 1992. AB3098 was implemented to ensure that all operations contained three things 1) a Use Permit or vested rights determination from the local agency, 2) a reclamation plan to outline what will happen with the operation when completed and 3) financial assurances that the reclamation plan can be completed. If operations are not found to comply with the requirements of AB3098, they will not be placed on the AB3098 list and therefore cannot sell their product to the State of California.

Aggregate is primarily used for construction—predominately for road base and concrete components. The California Department of Transportation (Caltrans) is a major aggregate consumer, utilizing approximately 20 million tons of sand and gravel in 1991 (Crossett, 1993). Caltrans estimated that aggregates account for 8-10% of total project costs[3]

According to the Department of Conservation, there are 10 historical mines upstream and three ongoing operations upstream of the Hickman Road Bridge and another partially off-channel project planned. The impacts of the gravel mining operations are exacerbated by the construction of Don Pedro Dam and Reservoir in 1971. The reservoir cuts off sediment that would otherwise travel downstream the Tuolumne River reducing the annual replenishment as shown in Figure 12.

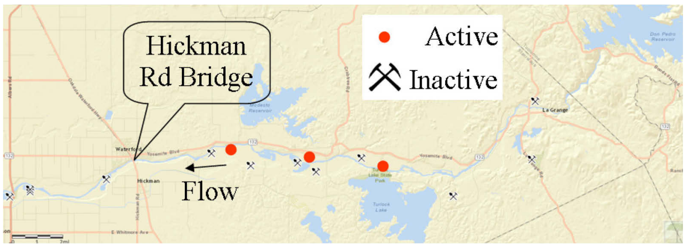


Figure 12: Active and Inactive gravel extractions on the Tuolumne River in Stanislaus County (from California Department of Conservation

According to a report by Stillwater Sciences (Stillwater, unknown), large scale aggregate mining operations began in the 1940s and continue today. Historic mining included in-channel pits as much as 120 meters wide and 10 meters deep. These pits occupied 32% of the length of the channel in the gravel-bedded reach. More recent operations have extracted material from adjacent terraces similar to the San Benito and Sonoma Counties. The terrace pits which are separated from the active channel by alluvial berms which are merely unexcavated alluvial material The Stillwater report noted that the "unengineered berms have failed even during moderate flows, resulting in direct connection of the pits to the river channel. The January 1997 flood, which peaked at nearly 60,000 cfs (1,700 cms), caused extensive damage in the mining reach, breaching nearly every pit berm" (Stillwater, unknown).

There are no available sediment transport or geomorphological studies estimating the local or cumulative imipact of gravel extraction to adjacent infrastructure. A recently proposed reclamation plan for a new extraction operation upstream from the Hickman Road Bridge shows a proposed extraction site without any hydraulic analysis. Even the depiction of the 100-year floodplain limits as shown in Figure 13 is based only on an approximate study by the Federal Emergency Management Agency. A small berm will separate the proposed 12 meters deep excavations from the existing approximate stream channel, almost guaranteeing that the operation will someday become part of the active channel.

[3] http://www.calcima.org/html/fast_facts.html, accessed June 2, 2016.

Figure 13: Proposed operation with approximate FEMA floodplain overlain (EnviroMINE, 2008)

This information along with a search on google earth show widespread gravel operations still operating in and immediately adjacent to the channel. The available maintenance records for the bridge have cross sections from 1972 to 2014 and are plotted in Figure 14. Avila found a significant error in the 1997 section in which the inspector missed a span when they obtained the cross sectional data. As a result, the missing cross section was not used. The plot shows that the channel thalweg degraded approximately 2 meters in approximately 50-years from elevation 65-ft in 1963 to elevation 59-ft in 2014. If the channel continues at the same rate, it would degrade 1 meter in 25-years or 2 meters in 50-years. This degradation is likely to expose more of the pier footing and undermine the current pier scour countermeasure, which will result in an increase of local pier scour.

According to the National Bridge Inventory System (NBIS), scour is currently given a rating of 3, which means that the bridge has been determined to be scour critical (FHWA, 1995). Scour has been repeatedly noted during biennial inspections due primarily to exposure of the pier footings. Scour countermeasures in the form of A-Jax were installed in 2004 by Stanislaus County. These A-Jax have not performed well since their installation as documented in the BIRIS reports which note deterioration, settlement and displacement (Stanislaus, 2011). Like the Alexander Valley Road bridge documented above, the Hickman Road Bridge has foundations at differing elevations assuming the channel migration does not occur.

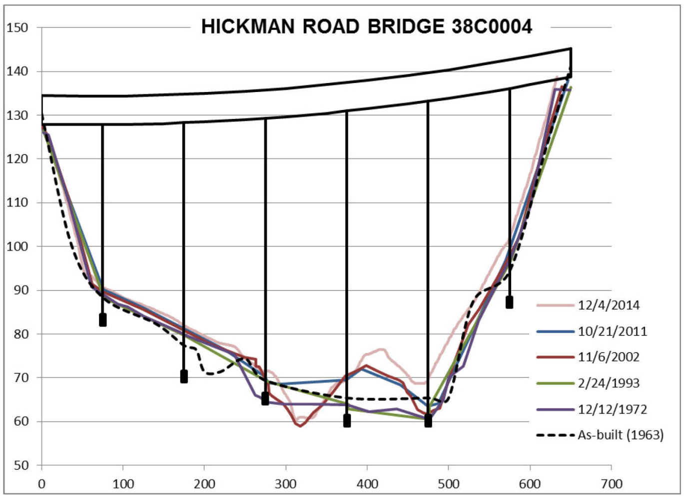


Figure 14: Channel Sections at the Hickman Road Bridge over time from 1963 to 2014

Figure 15: Exposed Hickman Road footing protected by "A-Jax"

5 CONCLUSION/RECOMMENDATIONS

Instream gravel mining in California has been significantly reduced or eliminated in many parts of the state. Many of these operations have merely moved to the adjacent terraces where off channel pits are not truly off channel and larger flood events can cause these areas to become instream operations with all the potential negative impacts associates with instream operations. Increase awareness of the impacts to instream infrastructure and threats of curtailing federal funding to replace bridges impacted by gravel operations have help local agencies to consider both the potential economic benefit of providing mining jobs to their constituents as well as the cost of replacing very expensive bridges without 88.47% matching funds from the FHWA.

As a major consumer of sand and gravel, Caltrans could utilize the AB3098 list to "blacklist" any operations that are proven to be causing degradation adversely impacting bridges and "greylist" operations that are suspected of causing degradation until sediment transport and/or geomorphological studies can be completed.

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