PRECAST- PAVEMENT AS A HIGHWAY MAINTENANCE STRATEGY

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ABSTRACT

California Department of Transportation (Caltrans) Maintenance crews are challenged to keep aging concrete pavements in serviceable condition with limited resources, and to reopen to traffic as soon as possible. Repairs often occur on an emergency basis, under adverse weather and traffic conditions. Based on the success of other precast pavement projects, the Maintenance Division in Los Angeles has developed a non-proprietary jointed-precast-concrete pavement system as a cost effective, durable and sustainable strategy to replace damaged concrete pavements and return them to traffic as soon as possible.

Since 2012, in-kind pavement thickness installations have been placed in curved and tangent alignments, in heavy drizzle and near freezing temperatures, on several routes, and opened to traffic within 6 hours; this would normally not be possible with other Maintenance strategies. To demonstrate sustainability, previously installed precast panels were removed, salvaged, transported and reinstalled at another location in 2014. Stockpiles of precast panels have strategic benefits for temporary roadway, emergency pavement repairs, and during disaster recovery operations. Base support, slab-leveling devices, and load-transfer systems have also been evaluated.

Caltrans Highway Maintenance crews now have a state-of-the-art, durable, cost effective and sustainable concrete pavement repair tool, to keep roadways open in all weather conditions.

KEY WORDS: Precast Pavement, Maintenance Strategies, Non-proprietary Jointed-precast-concrete pavement system, Sustainability, Disaster Recovery, Temporary Roadway.

INTRODUCTION

State Highway Agency (SHA) Maintenance crews in heavily traveled urban areas face the daily daunting task of keeping aging concrete pavements in serviceable condition with limited resources under incessant public demand to open them to traffic as soon as possible. Frequently this work must occur on an emergency basis, under adverse weather and traffic conditions.

Anyone who has participated in construction or maintenance work in an urban setting, next to live traffic understands the adverse safety aspects of closing urban freeways to conduct pavement repairs. Night and adverse weather conditions only increase the potential for jeopardy to the Maintenance team and the travelling public.

Typical SHA pavement repair strategies have included hot mix asphalt patches, cold mix asphalt patches, accelerated concrete mixtures, and other proprietary materials. Performance of these strategies has often met with mixed success, due to poor compaction, wet and cold or near freezing night time conditions.

Innovations to achieve longer lasting repairs have included rapid-strength-gain accelerated concrete mixtures, but these often have durability limitations due to in-kind replacement thicknesses, various methods of acceleration, and poor strength gain[1] before opening to traffic. The typical life of these repairs can often be less than 2 years[2].

Unless there is a viable alternative to the status quo, the financial cost in tax-payer dollars and human lives due to repeated repairs will continue unabated. State-of-the-art technology, which allows longer lasting repairs must be employed to realize improved safety from less exposure to live traffic conditions, in addition to cost savings realized from more durable strategies and less frequent repairs.

A VIABLE ALTERNATIVE TO THE STATUS QUO

While the California Department of Transportation (Caltrans) was looking for other strategies to improve long term performance of concrete repairs in design and maintenance applications, the University of Texas at Austin was conducting Federally-funded research on precast concrete pavements at a test site in Georgetown, Texas[3].

Caltrans engineers in Los Angeles, immediately recognized the significance of this work, as a state-of-the-art technological solution to improve the constructability, durability, and early opening challenges they had been facing with other repair strategies. They began a dialog with the Federal Highway Administration, the Transtec Group, and the Precast Concrete Manufacturers Association of California (PCMAC) to construct a demonstration project in El Monte, California, a suburb of the greater Los Angeles area[4].

Upon completion of the demonstration project in El Monte, additional precast concrete pavement installations were proposed, and additional research into an alternative jointedtype of precast concrete pavement followed[5]. This additional research verified that jointed-precast-concrete pavement systems can produce a durable concrete pavement replacement strategy[6].

A WILLINGNESS TO INNOVATE

A willingness to try a new promising strategy might be a logical choice, may be a leap of faith, or considered foolhardy. How many times do we hear the phrase, "If it ain't broke, don't fix it."

It may take a long time for someone who is used to doing things they way they have always been done, to realize the status quo of repeated pavement repairs is unacceptable. It may take longer before this same situation can no longer be tolerated and there is a willingness to try something different.

Many people working in a bureaucracy are conditioned to accept the status quo, and leave innovations to someone who is less risk-adverse. SHA workers are used to working in a bureaucracy, so it comes as some surprise when someone is willing to go out on a limb, voluntarily be a member of an innovative team, and try something very few of your peers is willing to attempt. While Caltrans Mission and Vision encourages employees to be an innovative team member, with integrity and stewardship in mind[7], it can mean stepping outside one's comfort zone.

In the north region of the Los Angeles Caltrans Maintenance Division, the status quo of repeated pavement failures became sufficiently intolerable to try something innovative. The combination of heavy traffic, high water table and age had taken its toll; many sections of roadway had been repaired and had failed within 5-years. (Fig.1)[8]

Fig. 1 Existing failing pavement condition on Route 210 near Montrose, CA.

The first installation conducted by Caltrans Maintenance forces, was on Route 210 in Montrose, California, in 2012. The jointed-precast-concrete pavement system selected for this demonstration was a proprietary system also used on Route 210 in Fontana in 2005, and was backed by research conducted by the University of California Pavement Research Center (UCPRC)[5].

The damaged concrete was removed, the existing cement treated base was repaired, (Fig. 2)[9] or ground down where it was too high, a layer of granular bedding with 1:6 ratio of cement to sand, by weight, was compacted and wetted. Plastic sheeting was placed to confine grout under the panels, and an in-kind slab thickness of 8" was placed, (Fig. 3)[10] followed by under-slab grouting. The work was conducted at night, in November with a 6' traffic buffer, separated by reflective plastic cones. Several other Maintenance crews and engineering personnel, attended to see the new precast panels be installed. (Fig. 2)[9]

Fig. 2 Base preparation of precast pavement installation on Route 210 near Montrose, CA. Devorkin, S.[9]

Fig. 3 Installation of precast pavement on Route 210 near Montrose, CA.

While this was considered a milestone for the Maintenance Division, and a successful installation, several of the steps involved in the base preparation and placement of granular bedding seemed overly time-consuming. It took more than 8 hours to place 5 precast panels. A similarly sized cast-in-place project would have taken 2 hours plus the curing time, which can be as little as 2 hours, or as long as several days[2].

The cost of the panels were approximately $25 per square foot, equivalent to $1,000 per cubic yard. In most cases during this time period, this was double the cost of cast-in-place rapid strength concrete pavement[2]. Instead of discouraging the team, it became an incentive to make the system more constructible and cost effective.

Due to the potential for constructability improvements and cost savings, Caltrans engineers in the Divisions of Maintenance and Design collaborated with PCMAC and contractors to design, fabricate, and successfully install a non-proprietary jointed-precast-concrete pavement system. In addition, they addressed the concerns of constructing uniform "flat" panels in a tangent alignment, and trapezoidal "flat" panels allowed them to follow a curved alignment. Working with the construction crews and fabricators, each new installation improved the production rate of the installation and reduced the cost of panels.

During two significant 40-panel installations, one on Route 210 in Altadena, and on another on I-5 near Lake Hughes Rd. the work was done in 6 hours, at night in heavy drizzle and near freezing temperatures, in a curved and tangent alignment, respectively, with a cost per panel of $12 per square foot.

Both productions included repairing the base with rapid setting lean concrete base (LCB) instead of granular backfill, (Fig. 4)[10] which took much less time to place, using plastic sheeting for grout confinement instead of proprietary gaskets, installing the panels, installing dowel bars in "retrofit slots" for slab to slab load transfer, and pumping under-slab grout.

Fig. 4 Constructing rapid setting lean concrete base for precast pavement on Route 680 in Dublin, CA.

A similarly sized cast-in-place installation would take approximately 10 hours with a 2-hour rapid-strength-gain mix, or longer, waiting for a slower mix to cure.

The cost of these optimized panels dropped to less than $500 per cubic yard, and became competitively priced with rapid strength concrete pavement. Clearly the team had made significant progress in a few months.

Thus far, the precast panels for these maintenance installations had been purchased from a fabricator through Maintenance Division purchase order agreements, building upon the fabricator's shop drawings to customize and improve each project, and installed under a separate service contract with an innovative construction vendor.

Once several projects had been constructed, and an optimized constructible, cost effective strategy had emerged, the next logical step in the progression of Maintenance Division work was to develop Standard drawings, and specifications, and add formal competitive bid contracts to replace damaged concrete pavements on a regular, non-emergency basis. This work proceeded in the 2013-14 design cycle, that delivered 4 competitively bid projects for the 2014-15 construction season.

PRECAST PANELS ARE COST EFFECTIVE

While it may seem intuitive that an 8" reinforced concrete panel, with two mats of steel would out-perform an unreinforced concrete panel of the same dimensions, the magnitude of performance difference is not intuitive, as evident from discussions with various Caltrans pavement committee members; in the absence of test data there has been a widely held belief in the theory that there is no significant performance difference by adding reinforcement to concrete panels.

A sign posted at the Caltrans Materials Engineering Testing Services (METS) Laboratory in Sacramento, reads, "One test is worth a thousand expert opinions", and Igor Sikorsky, helicopter designer, expressing a similar sentiment, told his students, "In the course of your work, you will from time to time encounter the situation where the facts and the theory do not coincide. In such circumstances, young gentlemen, it is my earnest advice to respect the facts." Further testing of the jointed-precast-concrete pavement system would bear this out[6].

The Highway Design Manual (HDM)[11], provides a method to determine the required pavement thickness, based on a design Traffic Index (TI), for a specific pavement design life. The pavement design life is calculated by multiplying the Annual Average Daily Truck Traffic (AADTT) from a biannual Caltrans traffic count for 2, 3, 4, and 5-axle trucks, for a specific section of roadway[12], by a 10, 20, 30, or 40-year Equivalent Single Axle Load (ESAL) constant from Table 613.3A[11], and summing the total. The total ESALs for the design period is converted to a TI using Table 613.3C[11]. The design TI is used to identify the correct pavement thickness in the Rigid Pavement Catalog, Table 623.1G[11], for a jointed plane concrete pavement (JPCP) with dowels and treated base support[11, 13].

Based on the above method, a table of pavement thicknesses shows the corresponding ESALs which a typical existing pavement thickness can withstand during the expected pavement life. In-kind thicknesses can be evaluated for expected design life. (Table 1)[12]

TABLE 1 Capability of Existing Pavement Depth to Support Traffic Loading, in ESALS

PAVEMENT THICKNESS	EQUIVALENT SINGLE AXLE LOAD (California Coastal Climate)	EQUIVALENT SINGLE AXLE LOAD (California Inland Valley Climate)
8” (20 cm)	**< 800, 000 ESALS**	**-**
9” (22.5 cm)	**3,020,000 ESALS**	**< 800, 000 ESALS**
10” (25 cm)	**13,500,000 ESALS**	**6,600,000 ESALS**
12” (30 cm)	**84,700,000 ESALS**	**26,100,000 ESALS**
14” (35 cm)	**238, 000,000 ESALS**	**84,700,000 ESALS**
16” (40 cm)	**-**	**238, 000,000 ESALS**

A heavy vehicle simulator (HVS) applies accelerated loading, and is frequently employed in research to apply accelerated loading to determine if a proposed pavement strategy has merit, in a shortened time frame. Failure can be achieved in a matter of months, instead of decades. A very good estimate of the pavement’s strategic potential can be evaluated and accepted, or rejected, before significant time and dollar investment is placed in poorly performing strategies. Caltrans employed such a method to determine whether a jointed-precast-concrete pavement system was worthy of future development, investment, and deployment[5].

The research conducted with Caltrans HVS equipment, conducted by Dynatest through a research grant with UCPRC in 2006, on an 8” jointed-precast-concrete pavement test section, on the I-210 in Fontana, CA[6], showed no distress after application of 142 million ESALs. To accelerate pavement failure more rapidly, researchers applied an airplane load to reach 242 million ESALs, until the pavement failed by crushing. The HVS testing demonstrated that similar in-kind thickness precast pavement sections are expected to survive better than 240 million ESALs before failure occurs.

Conversely, a field condition survey conducted in June 2013, of multiple locations of poured-in-place 8” and 9” concrete panels on I-210, near Montrose, CA, had not withstood 5-years of traffic loading, approximately 19.8 million ESALs, for this section of roadway[12, 11]. This field condition survey demonstrated that an in-kind thickness of poured-in-place concrete panels is more likely to have a low survival rate, than the equivalent thickness of jointed-precast-concrete pavement sections, which can accommodate as much as 12 times more ESALs before failure occurs.

The jointed-precast-concrete pavement systems are cost effective because of the significantly improved pavement durability, for an equivalent expenditure. At twice the cost, the precast panels were still 6 times more cost effective.

Other costs of "doing business" include lane closures, employee overtime, driver user-delays, worker and driver exposure to traffic hazards during lane closures, (Fig. 4)[10] mining and transporting the raw and manufactured materials. These additional costs and resources could be used elsewhere on other more critical needs.

An additional reason why precast-concrete pavement systems are cost effective is sustainability.

PRECAST-CONCRETE PAVEMENT SYSTEMS ARE A SUSTAINABLE STRATEGY

When a pavement or other strategy can show a significant reduction in the use of the local mineral or natural resources, a reduction in energy use, and no new mineral or energy resources are needed to maintain the strategy, this would be a reasonable definition of a sustainable strategy.

Whether such a goal can be achieved indefinitely, requires a significant shift in the way Maintenance workers, Engineers, and others think and behave, about pavement, about worker exposure to traffic, about driver expectations, about transportation, about use of taxpayer dollars, and about construction and maintenance strategies.

It seems that precast panels are at least two steps closer to being a sustainable strategy. The first is the long-term performance that these reinforced, approximately 8" thick panels have shown to exhibit based on HVS testing[6], whereby the precast-concrete panels sustained significant traffic loading, equivalent to several years of loading[12, 11], without exhibiting distresses or failure.

The second is that these thinner panels use fewer mineral resources than their equivalent 14" to 16" JPCP pavements, and that the need to replace a panel after 240 million ESALS saves transportation, energy, financial resources and improves productivity hours better than a panel that needs replacement in less than 19 million ESALs. The same is true about improving worker and driver safety. At this juncture, it seems fair to say that the jointed-precast-concrete pavement system is more sustainable than several other less durable pavement strategies that require multiple cost and resource expenditures for each repeated repair.

Although it has been argued that a 20 or 40-year strategy is unnecessary, because patches only need to last until next summer, until the next construction project is scheduled, or perhaps until "the rain stops", salvaging and reusing the precast panels at another location is a significant innovation, because it saves the initial investment in energy, mineral resources, and cost to fabricate the precast panels. (Fig. 5)[14] Although new costs of removal, panel clean-up, transportation and labor for salvage will be incurred, significant reduction in time, environmental and financial impacts are realized when the panels can serve their intended repair purpose again and again.

Fig. 5 Salvaged precast pavement on Route 15, San Bernardino, CA.

On Route 210, near Montrose, approximately after 1 year of service, several of the panels were settling and water was pumping under them, similar to the panels in the HVS test in Fontana[6]; members of the Caltrans precast panel team agreed it would be an excellent opportunity to see how the granular bedding material had performed, and examine other aspects of the precast panel condition.

When the perimeter of the panel was sawed, the holes for the lifting devices were cleaned out, and the panels lifted out of the roadway, the team members could see that the granular bedding material was completely saturated and significantly eroded; the erosion was due to the flow of water under the panel, (Fig. 6)[14] very similar to the disposition of granular bedding material at the HVS test site, in Fontana, CA[6]. However, the panel was in excellent condition, and although it had settled several inches under the full traffic loading in the outside truck lane, it did not exhibit any noticeable distress or other failure mechanisms.

Fig. 6 Saturated subgrade condition under precast pavement.

While the panel removal showed that the precast panels perform well under adverse conditions, the underlying granular bedding material and bedding grout is highly erodible, and not a sustainable feature of the system. It also demonstrated that the panels could be easily removed, transported and reinstalled, if necessary.

This forensic look at removing and examining the precast panel, confirmed the working theories of four additional team premises:

1. Since precast panels can be salvaged and reused, up to and potentially exceeding 240 million ESALs, they are, therefore, highly sustainable. (Fig. 5)[14]

2. Since the precast panels can be salvaged and reused, they can be stockpiled as temporary pavement, and used during a disaster recovery situation, or other crisis. (Fig. 7)[14]

Fig. 7 Precast pavement and hot-mix-asphalt taper used for temporary pavement on a truck lane near Sylmar, CA.

3. The highly erodible granular bedding layer is not a viable aspect of the design, and should be replaced with a more durable, non-erodable treated material, such as LCB.

4. A plastic sheet spread under and up the sides of the panel is an effective method to confine the under-slab grout, prevent it from being diluted by flowing water, prevent it from flowing to unwanted areas in or beyond adjacent pavements, and to conserve project resources and costs from excessive grout use. Alternative methods such as gaskets, or caulking are more labor intensive and costly to achieve the same results.

PRACTICE MAKES PERFECT AND MORE INNOVATIONS

The hallmark of any sustained improvement effort, is repeatability. Science experiments are considered valid once the same results can be achieved by others. In applied sciences, such as engineering, you are looking for both repetition and for improvements to optimize your system, make it safer, more constructible, more durable, more user friendly, more sustainable, and less costly.

On an SHA/Industry team, concerns frequently arise when innovations suddenly become the patented property of one of the participants, which take that innovation out of the public domain. This situation can stifle creativity and willingness to solve the project challenges or it can create competition among similarly beneficial solutions.

Two such features of the jointed-precast-concrete pavement systems exist. One is the device that levels the slab to match the existing roadway with minimal effort, and the other device provides the slab-to-slab load transfer. Each has benefits and challenges, champions and detractors.

LEVELING DEVICES AND METHODS

Proven leveling devices include:

- shims
- commercially available leveling bolts and hardware
- a leveling beam or bracket
- a patented composite leveling device system
- a rapid strength-gain
- under-slab grout
- a satisfactory method to level the base to the correct height for the panel

The two devices that seem the fastest with the fewest manual adjustments, are the leveling beams and a proprietary leveling lift system. Leveling beams straddle the panel, rest on the existing pavement, and are only removed once the under-slab grout is set-up. A proprietary leveling lift system has significant sacrificial hardware investment cast into the panel, bolts that stick up out of the roadway, and are removed when the under-slab grout is set-up. (Fig. 8, Fig. 9)[15, 14] Both leveling beams and leveling bolts can be reused, but a sufficient number of them are needed during the installation to keep all of the panels at the correct height while the grout is setting up.

Fig. 8 Panels installed with proprietary leveling and load transfer devices at Construction Yard, Glendale, CA. Parvini, M.[15]

Fig. 9 Precast pavement installed on a curve on Route 101 near Studio City, CA.

Shims and standard leveling devices are also sacrificial components, however require much less up-front investment in potentially costly hardware; they are manually placed and adjusted, which may require lifting-up and readjusting the slabs frequently, if the installer is not skilled at using them. This can decrease installation productivity, and result in delays to open to traffic.

Another option, which requires competent base finishing skills, is to construct the treated base support material so the panel is at the correct height to be level with the existing pavement. (Fig. 4)[10] This alternative requires virtually no leveling hardware and minimizes the quantity of grout needed to fill any under-slab low spots or voids.

LOAD TRANSFER DEVICES

There are several load transfer devices that permit slab-to-slab connections and transfer load across the joint.

Several effective joint details use round smooth pavement dowels[13]. Two of them have a slot for the dowel, with one end cast into the slab, and the open slot end fits over or under the dowel, respectively. The portion of the slot is backfilled with a durable dowel grout, such as polyester concrete. The system with the slot facing upward is non-proprietary. (Fig. 9)[14]

Another non-proprietary system has two upward facing slots, and the load transfer device is a smooth pavement dowel, constructed as if it were a dowel bar retrofit (DBR)[13]. In most cases the backfilled slot will be noticeable for the life of the pavement. (Fig. 5, Fig. 9)[14]

A third very effective non-proprietary method is a panel which uses a key and keyway system and post tensioning ducts to keep the panels aligned and tight. The tolerances on these panels are less forgiving, require more contractor skill, and attention to detail, to make sure the post-tensioning strand is handled safely and the duct is grouted correctly and fully. This is generally not considered a precast-jointed-concrete pavement system, but rather a precast pre-stressed pavement system[3, 4].

Lastly, there is a proprietary dowel-in-sleeve system, which has a small vent hole over the internal sleeve, and a small access pocket to slide an 18” dowel across the joint, prior to filling the annular space with grout. (Fig. 8)[15]

Nearly all of these systems have been approved for use on competitive bid contracts, due to satisfactory HVS testing[6], or due to extensive DBR testing by Caltrans, Washington State DOT and many others, and are considered equivalent to DBR. Only the dowel-in-sleeve is currently undergoing additional falling weight deflectometer testing (FWD) testing to verify its load transfer efficiency. (Fig. 10)[15]

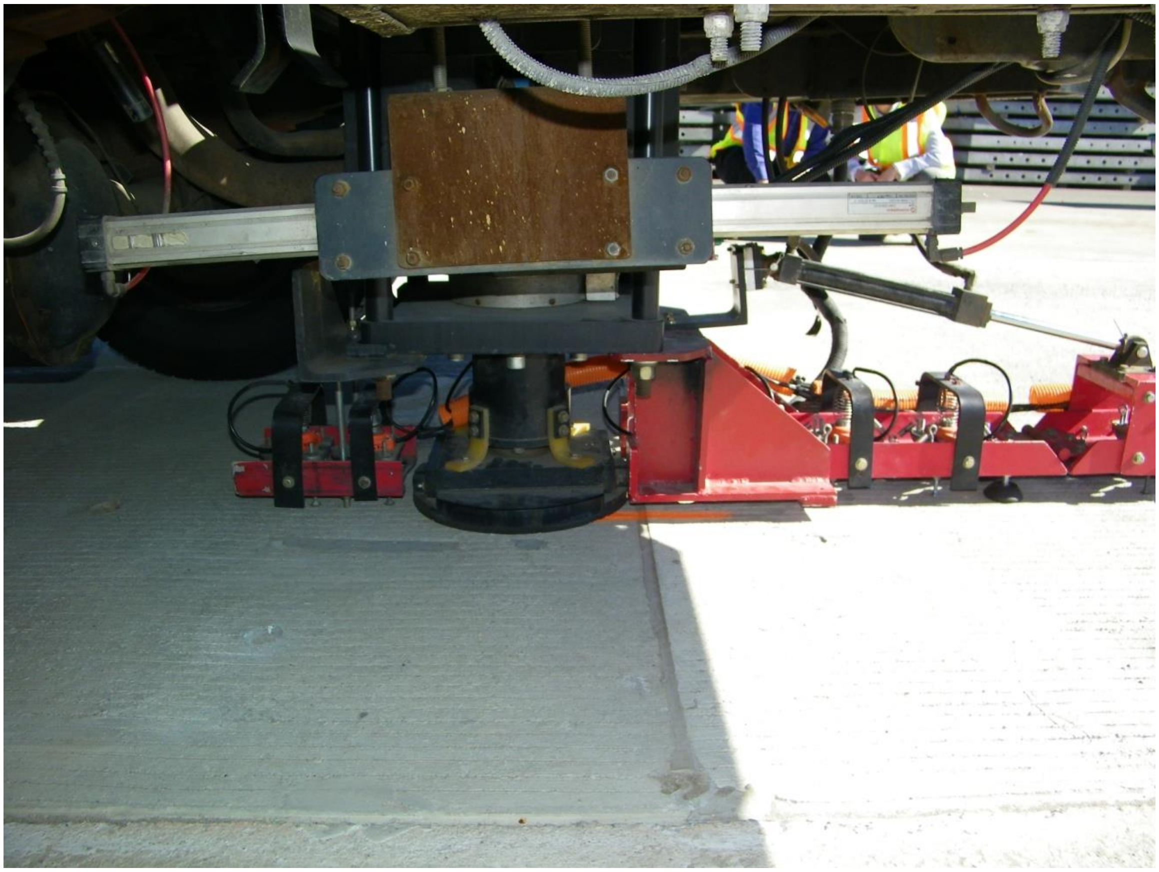

Fig. 10 Falling weight deflectometer testing (FWD) of a proprietary load transfer device at Construction Yard, Glendale, CA. Parvini, M.[15]

SUMMARY

SHA Maintenance teams who no longer wish to be caught in the cycle of repeated pavement failures and repairs, now have a viable alternative to the status quo of less durable strategies that tie-up their human and budgetary resources.

Based on previous installations, and supporting documentation from research and pavement design criteria, precast-concrete and jointed-precast-concrete pavement systems offer a durable, long lasting and constructible pavement repair and replacement strategy, Caltrans Maintenance Division in Los Angeles, committed a significant team effort to install, improve and optimize a jointed-precast-concrete pavement maintenance system.

This work was performed mostly at night, nearly always next to live traffic, and in many cases under adverse weather conditions.

Many innovations to improve constructability, reduce costs, improve safety, and open sooner to traffic were conceived and implemented to create a state-of-the-art non-proprietary precast-concrete pavement system. (Fig. 11)[14]

Fig. 11 Precast pavement to replacements ready to open to the morning commuter, on Route 10, in Los Angeles, CA.

The concurrent development of standardized construction details and specifications have allowed several Caltrans project delivery teams to employ these same innovations for long-lasting, cost effective and sustainable strategies in the 2014-15 construction season on four competitive-bid, in-kind, pavement rehabilitation projects. These four projects are currently under construction by different contractor and SHA teams, with members of the jointed-precast-concrete pavement implementation team providing technical support and recommendations upon request.

RECOMMENDATIONS

The following recommendations will allow the maximum benefit to be realized from this work:

1. Experienced jointed-precast-concrete pavement implementation team members need to continue to advance the state-of-the-art systems by updating construction details and specifications to improve constructability, and implement innovations on maintenance repairs and competitive-bid contract projects.

2. Experienced jointed-precast-concrete pavement implementation team members must continue to provide insight and technical support to others who seek to utilize precast-concrete pavement strategies.

3. Maximize salvage and reuse of precast panels due to pavement reconstruction or other activities that displace them.

4. Stockpile precast panels for use as temporary pavement during routine construction, emergency repairs, disaster recovery, or other crisis.

5. To the extent possible, replace erodible granular bedding layers with durable treated bedding materials, such as LCB.

6. Use a plastic sheet under and up the sides of the precast-panels to confine the under-slab grout, to prevent it from being diluted by flowing water, to prevent it from flowing to unwanted areas, and to conserve project resources and costs from excessive grout use.

7. Continue to document costs and durability of in-kind replacements compared to precast-concrete pavement replacements.

8. Continue to embrace innovations that enhance the constructability, safety, sustainability and cost effectiveness of precast-concrete pavement systems.

9. Continue to provide supporting test data that demonstrate the effectiveness, durability and sustainability of innovative components in precast-concrete pavement systems.

CONCLUSIONS

Experience, innovations, and lessons learned from each installation, have resulted in a cost effective, early opening, safe and sustainable strategy for in-kind pavement maintenance repairs, and give Highway Maintenance crews a state-of-the-art, durable, cost effective and sustainable tool, to keep roadways open in all weather conditions.

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LIST OF FIGURES

REFERENCES

1. Unpublished test results, on Route 60 in Pomona. 1997. California Test Method (CTM) 523. California Department of Transportation.
2. Stahl, K. Unpublished case studies of pavement failures and repairs. Various dates. California Department of Transportation.
3. Merritt, D. K., McCullough, F., Burns, N. H., and Schindler, A. K. The Feasibility of Using Precast Concrete Panels to Expedite Highway Pavement Construction. Publication FHWA/TX-01/1517-1. Texas Department of Transportation.
4. Merritt, D. K., McCullough, F., Burns, N. H., and Rasmussen, R. O. Construction of the California Precast Concrete Pavement Demonstration Project. Publication FHWA-IF-06-010. The Transtec Group.
5. Kohler, E., du Plessis, L., and Theyse, H. Construction and Preliminary HVS Tests of Pre-Cast Concrete Pavement Slabs. Publication UCPRC-RR-2006-10, University of California Pavement Research Center, Davis and Berkeley, California.
6. Kohler, E., du Plessis, L., Smith, P. J., Harvey, J., and Pyle, T. Precast Concrete Pavements and Results of Accelerated Traffic Load Test. California Department of Transportation. (Caltrans).
7. Caltrans Mission, Vision and Goals. 2015. California Department of Transportation.
8. Toledo, E. G. California Department of Transportation. Photograph. Various dates.
9. Devorkin, S. California Department of Transportation. Photograph. Various dates.
10. Stahl, K. California Department of Transportation. Photograph. Various dates.
11. Highway Design Manual. March 7, 2014. California Department of Transportation (Caltrans).

12. Annual Average Daily Truck Traffic on the California State Highway System. 2013. California Department of Transportation (Caltrans).
13. Standard Plans. 2010 Edition. California Department of Transportation (Caltrans).
14. Wong, D. California Department of Transportation. Photograph. Various dates.
15. Parvini, M. California Department of Transportation. Photograph. Various dates.