BRIDGE RETROFIT CONSTRUCTION TECHNIQUES

By Patrick Hipley
Office of Earthquake Engineering - Seismic Technology Section

Presented at the
SECOND NATIONAL SEISMIC CONFERENCE ON BRIDGES AND HIGHWAYS
Sacramento, California - July 8-11, 1997

Introduction

The retrofitting of bridge structures is primarily to prevent loss of life due to collapse of bridges in large seismic events. As a by-product of collapse prevention, a great economic benefit can be realized because a retrofit bridge will experience limited damage. It is much less expensive to replace columns and repair hinges than it is to replace the entire structure.

The most destructive earthquake failure mode for bridges is the unseating of in-span hinges. Since in-span hinges are not designed to cantilever, that entire length of span will drop possibly causing a domino effect that will destroy much of the structure and gravely endanger the traveling public.

The second most seismically vulnerable aspect of a bridge are the columns. These members hold the structure up and if they shear or are weak in flexure, the structure may also experience a catastrophic failure. Other retrofits such as in-fill walls, catcher blocks, foundation work, etc. will be discussed.

Hinges

Inadequate hinge seats (12" or less) are typically retrofit using cables or HS rods to "stitch" the joint together in conjunction with pipe seat extenders. Small bolsters are usually placed against each existing diaphragm to allow for more "bite" into the existing girders, deck and soffit. The bolster also allows for anchorage of the fixed end of a pipe seat extender.

The first order of work, after providing access, is to clear out any form-work left in the work area, then core the holes for the cables and pipes through the existing diaphragms. These cored holes should be placed a few inches above or below the hinge seats main transverse reinforcement and centered in the bays. The cored holes should clear the hinge seat faces by at least 6 inches to avoid cutting any transverse bars or the bearings. If cable restrainers are used for moderate to well seated structures (12" or greater), the designer usually extends the cables back to the first intermediate diaphragm to allow the longer cables to elongate farther prior to failure. This allows the joint to have controlled flexibility with large deflection capacity. For box girders, the soffit access opening should be made permanent to allow for future inspection. The hole should be close to the work but far enough away to allow room for the new bolster and a ledge to work from. The opening should be sealed with a plate. For tall canyon bridges where it is impractical to access the soffit, access through and repair of the deck is an option.

Cable restrainers are typically a group of 5 - 3/4" diameter 7 strand twisted cable having a 50 kip breaking strength. The cable groups are run through two cored holes placed side by side to allow the cables to run through one hole and back through the next. This facilitates the manufacturing of only one cable to cross the hinge twice. A steel bolster is placed on the non-anchorage side of the hinge to create a rounded smooth transition as the cable passes from one hole into the next hole to avoid kinking. The new concrete diaphragm bolster (if needed) is blocked out to extend the cored hole raceway to the edge of the bolster. The cables are anchored by placing a swaged fit threaded rod to bear a nut against a thick bearing plate that accommodates the whole cable group. Once the retrofit is complete, a shim is placed between the nuts and the bearing plate to allow for thermal movements, and the cables are tightened snug. The shim thickness may vary depending upon if it is winter or summer as the hinge retrofit is completed. The shims are then knocked out. Thread locking fluid (liquid plastic) should be placed on the threads just prior to the final setting to keep the nuts from drifting under vibrations.

Pipe Seat Extenders

Raceways are also blocked out for the placement of pipe seat extenders through the new diaphragm bolsters. The pipes are typically 8" diameter XX-strong pipes (un-grouted) anchored (fixed) at one end and free to slide at the other end. The fixed end of the pipe is usually the bearing side of the existing hinge. Thus the pipe should be shimmed up to bear at the top of the cored holes prior to the grouting of the fixed side cored hole. The free end of the pipe should have construction paper wrapped around it in the region of the cored hole to guarantee slippage. Once the pipe is blocked up to the top of the cored holes, the fixed end should be sealed near the hinge gap by pushing in material or using expandable foam. The void is then pressure grouted. This reduces the length of cantilever action needed by the pipe if it should take the entire unseated load. It is imperative that no grout enter the hinge gap. Dowels should be placed on all vertical surfaces in the region of the new bolsters to laminate the new pour to the existing structure. Avoid placing dowels in areas using pre-stressed strands. Place the reinforcement in the new bolster and seal the form-work for the concrete pour. If the deck can be accessed, 6" cored holes can be drilled to allow for concrete placement and vibration then just fill the holes with the bolster concrete. For busy highways, shutoff valves can be placed on the inside form-work to allow pumping of pea-gravel concrete and the valves are shut once the void is filled. Windows in the top of the forms are needed to vibrate the concrete and can be sealed as the concrete reaches this level. Another option is to leave the form down six inches from the deck, pump the concrete and vibrate through this space, then hand pack(dry pack) the top portion of the bolster later. The pipe can be fixed to the bolster by drilling holes through the pipe and double nutting bolts to the end of the pipe. Studs can also be welded to the pipe to create fixity.

The pipe usually carries 6 to 12 inches beyond the edge of the bolster face on the free end. Sometimes a plate is welded to the end of the pipe to limit the ultimate gap expansion. If the situation will allow it, the cables can be run through the hollow section of the pipe and the pipe anchorage can be modified (studs welded to outside) to accommodate this passageway.

Columns

Columns are retrofit utilizing welded A36 steel casings ranging from 1/4" to 5/8" in thickness. Steel casings are made circular or as close to circular as practical using an elliptical shape for rectangular columns. The shells are pre-manufactured in two or more sections then field welded to encircle the column. A gap of 2 to 4 inches is left at the top and bottom of the column. If the superstructure has a steep super elevation this must be accommodated for by the casing. For circular casings, a minimum one inch gap is left all around and the void is filled with grout. The grout is pumped from the bottom up to guarantee no air gaps will be created. The grout must be placed slowly and symmetrically to avoid pushing the can to one side or the other by the fluid pressure. Small bars (l" x 1/2" x 3") should be welded to the inside of the shells to maintain the minimum one inch gap at all times. Injection ports for the pump will need to be spaced vertically depending on the capacity of the pump used. Once the grout spills over the top edge, the can should be filled with grout. Once the grout has cured (2 days or so), the top of the casing should be hand packed with mortar to fill any shrinkage voids and to form a slope to drain.

Elliptical steel casing requires more effort to grout. If any annulus gap in the shell is more than four inches, pea-gravel and sand should be added to the grout to reduce shrinkage. The elliptical casings tend to form a circular shape when grouted. That is, the long side tries to push outward by the fluid pressure and the short side will come inward. A bracing system can be used to hold the fluid pressure thus keeping the shell in the desired shape, but more commonly the grout lifts are just limited in height to keep pressures low. If a grout lift is only 10 or 15 feet in height, the fluid pressures may be small enough so as not to excessively deform the casing. Pre-placed injection ports at the desired lift height will allow a continuation of the grouting operation the next day after the grout hardens. Once the grout hardens it locks that portion of the casing in place.

The initial seal for the grout at the bottom of the casing is done in various ways. The casing is usually placed on 2" tall reinforced concrete dobies to get the required spacing. One way to seal the base of the shell for grouting is as follows: Build 2 x 6 wood form-work around the perimeter of the shell and secure for grout. Hand mix or truck in concrete or grout and place up to the top of the form-work. By pushing the concrete with a stick, the hydrostatic pressure will force the mix a few inches into the bottom of the shell. When this hardens, the bottom is sealed. After the initial seal has set, some contractors place the first injection port a few feet up from the bottom of the shell and pump grout to the bottom of this port. Once this second seal is hard a better assurance against "blowout" can be achieved if high pressures are expected.

Any large permanent opening in the casing, such as drainage openings, will need added reinforcement welded to the outside of the shell to transfer the stresses.

The casings are painted with zinc rich primer prior to shipment on the inside and outside faces of the steel. The primer is held back 6" from any field welded areas to avoid the zinc being volatilized. The injection ports and lifting ears are removed and ground flush. Touch up primer is added at the completion of the job and prior to back filling. Partial height shells are commonly used to contain only the lap splice regions for single column bents.

In-fill Walls

An effective and relatively inexpensive means (cheaper than casings) of retrofitting multi-column bents for column shear are in-fill walls. 12 to 16 inch thick walls are placed between the columns to essentially create a pier wall bent. Dowels are placed at the columns, bent cap and footings to be encompassed into the new wall to laminate the new and existing members. By placing epoxy cartridge dowels into the bottom of the bent cap, longitudinal capacity (movement resistance) can be developed. The wall will prevent the shearing of the columns transversally and will create a stable base for the superstructure to rock back and forth longitudinally. Again, injection ports mounted to the form-work having shut off valves allows for the pumping of the concrete all the way to the top of the wall. Any rock pockets can be dry packed if not too severe.

Typically, #5 bars are placed at 12 inch spacing both horizontally and vertically on each face of the wall. #5 hooked bars are placed at each intersection to tie the two vertical mats together.

Alternative Column Casings

Composites are now in use as an alternative to steel casings in limited situations and show much promise in longevity and ease of installation. Three types of systems are currently approved by Caltrans. The first is an ambient cure 2 part epoxy E-glass hand lay-up system. An E-glass weave is saturated with epoxy resin and wrapped onto a spool. The spool is then wrapped by hand around the column in 54" tall sections butted together. A cable mounted to a running track is sometimes attached to the soffit to take the vertical load off the spool as it is walked around the column.

The second system is a pre-preg filament wound epoxy carbon fiber shell wrapped using an automatic winding machine. The machine encircles the column as it is geared to go up and down until the desired jacket thickness is evenly laid up. The jacket is then cured using heat blankets or a moveable oven that is hoisted up the column until 250°f is maintained for an hour.

The third system utilizes pre-manufactured Vinyl ester E-glass shells that are made with a diameter just less than the column's diameter. These shells are then glued to the column in sections using an epoxy adhesive. The final outer shell clamps to the next inner shell to create continuity across the split and each inner shell staggers the joints. The shells are flexible and are simply opened up to be placed around the column and then pop back into their original shape. Once all the shells are in place, straps or clamps are placed around the system to tighten up the jacket so the jackets are firm against each other until the adhesive is cured. This clamping needs to be done quickly.

The use of composites are a good tool if only the top of the columns need retrofit because it is glued to the column. For a historic structure composites can also be used where you don't want to change the shape of the members.

Catcher Blocks

The simplest and least expensive means of allowing the superstructure to "float" over the substructure in a large earthquake is to place seat extenders (catcher blocks) under the girders. Once the bearings fail or shear, the weight of the girders transfers to the catcher blocks to ride out the earthquake without a drop failure. Many structures have pre-cast girders or use steel girders that are separated over the bent. Having the bearing shear at the onset of strong shaking allows the superstructure to be isolated in the substructure thus reducing the load into the substructure. Placing catcher blocks to extend the seat capacity is relatively inexpensive compared to bearing replacement in which the entire superstructure will need to be jacked up at great hazard and cost. Most structures will never see a damaging earthquake.

The catcher blocks should be doweled into the face of the bent or abutment. They are typically 12" - 16" wide and are placed about one half to one inch from the bottom of the girder. Individual blocks are used to allow inspection and maintenance of the existing bearings. A beam can be placed along the entire bent face and the catchers can be projected upward right under the girders. This allows for the placement of more dowels along the bent face. If the loads are expected to be large on the catchers and the dowels are not enough to take the force, HS rods can be placed in cored holes thorough the bent cap. The rods can be embedded into the catcher blocks with anchor plates. This will allow better shear resistance to the blocks and will prevent "zippering" of the dowels.

Footings

Footing work tends to be the most difficult and costly of all retrofit measures. It should be avoided at all costs. Usually only single column bent structures need a footing upgrade because multi-columns can allow the base of the column top in thus increasing the structures natural period and reducing the shear to the column. A multi-column structure is stable with pins at the base of the columns, but single column bents become unstable transversely.

The extreme costs in footing work stem from the large excavations needed and the addition of new piles. Many times access roads need to be built just to get at the footing with heavy equipment.

The first order of work is to excavate to the footing top and around the sides if piles are to be added. If the footing is to be enlarged, the bottom mat must be exposed leaving 6" or more of the rebar sticking out. This is accomplished by chipping a 45° corner from the bottom of the footing until the bars are exposed. A better method is to remove the entire edge of the footing vertically. This can be done by placing expansive grout in a line of drilled holes or hydraulic rock wedges can pop off the edge. This concrete debris is removed.

Pile work will be the next order of work. The pile type used will reflect the most practical situation for the soil conditions. In many cases driven piles are selected for low overhead situations that may be encountered due to the height of the bridge. Low overhead pile driving is very expensive but can be achieved with clear distances down to 15feet. This requires welding many sections of pipe or H-beams to be driven in increments. Working only on the transverse sides of the bent is common to take advantage of the clear overhead space for pile driving or drilling.

If only uplift capacity is needed (i.e. spread footings on rock), tie-downs can be used to increase the footing's moment resistance. The tie-downs are anchored to an overlay pour on the existing footing and the tie-downs are drilled through the existing footing and anchored in the rock or soil. This is an option in remote canyon areas that have no access roads for driving equipment. Tie-down drills can be smaller and easier to manipulate.

All piles should be positively anchored to the new footing to create uplift resistance. The bottom mat reinforcement (if widened) can be extended by welding or the use of mechanical couplers. By having a vertical face on the footing, the mechanical crimping device can be lowered from the footing top directly. Also, if the bars are welded, the X-ray machine is easier to manipulate into position with a clear vertical footing edge to verify a proper weld.

Dowels are added to all faces that will receive new concrete. Typically these dowels consist of #5 bars embedded 8"with magnesium phosphate grout. The holes for horizontal dowels are drilled downward about 20° so the grout won't spill out.

Where possible, the new top and bottom mats should use seismic hooks to tie the two mats together. Seismic hooks are usually #5 bars with hooked ends that grab the top and bottom mats of a footing. These hooks are placed at the intersection of the mats, thus the mats need to be on the same lay-out. The new footing overlay ranges from 12 to 18inches thick and has two layers of steel (mats) of it's own. The first layer of steel is 1 1/2 inches from the top of the old footing and the other layer is 3" down from the top of the new footing. The horizontal bars go all the way to the edge of the new footing widening.

If lap spliced bars were used in the original bridge construction of the columns and footings, the new footing overlay will contain these bars thus creating a fixed base condition.

Bent Caps

Bent cap upgrades are uncommon because the caps tend to be stronger than the columns and are thus undamaged by large movements.

Upgrades of bent caps are basically the addition of two new beams on each side of the existing cap. These beams can be doweled into the existing cap and if needed tied together with HS rods through cared holes. If the bent upgrade is for a box girder bridge, holes can be drilled near the bottom of the girders so continuous bars can be passed through the holes. These bars can be mechanically coupled or lapped in the cells for continuity.

Steel Girder Continuity Plates

Steel plates can be used to sandwich the steel girder webs of simple span bridges. The plates are bolted to each web thus creating continuity across the joint over the bent. One side of the plate utilizes slotted holes to allow for thermal or rotational movements. The plates prevent unseating of the girders and create continuity longitudinally across the hinge (if the deck is not continuous over bent) and stiffness transversely across the bent. The plates are typically 1/4 to 1/2inches in thickness and many HS bolts are placed on each web. The fixed side bolts can be torqued and the expansion side (slotted holes) nuts can be snug tight and the threads locked. If the girder webs are not lined up or are skewed, the plates can be bent to fit or shim plates can be added to keep the plates in line with the girders. Vertical stiffening plates can be relocated a few inches away if more room is needed. Place new stiffener prior to removing old stiffener.

Strut Walls

Strut walls (usually used for pedestrian over crossings) are used to create stability, mostly transversely, but will add some longitudinal resistance also. The wall is sloped (pyramid shaped) from the superstructure to the footing in which new piles or spread footings are used to create a base for the walls. Rows of dowels are placed on the column faces and the existing footing top to create a monolithic system.

Anchor slabs

If a situation arises in which work to a vulnerable substructure is difficult and costly, (say a deep canyon) anchor slab scan be used to stabilize the structure at road level by driving the loads to the abutments. If the superstructure has a rigid transverse configuration (such as box girder bridges), stability both longitudinally and transversely can be achieved by creating a fixed moment connection at the abutments.

An anchor slab replaces the approach slab in which the new slab is anchored firmly with new CIDH piles or is simply a large concrete block. HS rods are cored through the existing diaphragm and are anchored into the new slab and bear against a new bolster placed in the superstructure. As the superstructure moves away from the abutment or tries to rotate in plane due to the transverse swaying of the middle of the structure, the new anchor slab is engaged and resists this motion. Thus the stiffness of the superstructure, by being fixed at the ends, will increase the transverse stiffness of the system. This is analogous to laying a deep beam on it's side and instead of having. a simply supported or free end condition, you create a fixed end condition increasing your rigidity. This retrofit measure saves a lot of work to the sub structure but is limited to short or moderately long bridges. The nuts for the bearing plates at the new bolsters should be backed off and locked to accommodate the thermal movements of the bridge.

Isolation and Dampers

Isolation bearings and dampers (shock absorbers) have limited use in bridge retrofit but are being used more for very vulnerable structures or extremely important structures such as Toll Bridges. Due to the cost to jack the bridge up to replace the bearing, typically simple seat extenders or catcher blocks are placed to take the load if the bearings fail. Once the bearings fail, the bridge is isolated.

Dampers are used for important structures in which much energy can be dissipated with large movements thus limiting the extreme movements and preventing more damage.

To replace an existing bearing with an isolation bearing enough headroom or space is required between the bottom of the girder and the seat face. Low profile isolation bearings are used if this space is limited. First the entire load is removed from the existing bearing and the girder is jacked up 1/16" to 1/8". This usually requires a jacking platform to be built out in front of the bearing under the girder, possible doweled into the existing bent cap. This can be left in place for future work on the bearing. Jacking frames built between girders are sometimes utilized to hoist the structure. Along with the expected dead-load, the jacking system should be designed to accommodate the live loads including impact. Bracing for sway due to traffic or other loads should be incorporated to prevent toppling of the jacks. The jackets should be all driven by the same hydraulic pump and raised at the same time to avoid stressing any cross members between girders. After the removal of the existing bearing, the new bearing is slid into place and shimmed up tightly to the bottom of the girder. Non-shrink grout is then pumped under the bearing and allowed to cure prior to removing the jacking system. Most isolation devices require the top and bottom plates to be bolted to the bridge members. The dampers can be connected to the substructure using heavy duty mechanical or chemical anchorage's and the other end bolted to the girders. Since an earthquake can shift a bridge in any direction, universal joints are recommended on each end of the damping device to prevent the shaft from being bent during movements other than axial. The damper should be set to the bridge in it's mid-stroke position or a position that takes full advantage of the free movements. The dampers are brought to the job site a bit longer than the mounted length and the piston is compressed slowly until the pin can be set into position.

Column additions or replacements

In extreme situations, column can be added or replaced to gain ductility and rigidity. If extra capacity needs to be built into a bent, new columns and footings can be placed between the existing columns for this purpose. Large diameter dowels are placed into the existing bent cap (avoiding damaging existing reinforcement) and a new column can be built under this location to strengthen the bridge. The dowels can either be placed in a pinned or fixed column configuration depending on the needs. This work is almost always difficult and costly and usually impractical.

Another extreme retrofit measure is column replacement. A bridge is jacked up to relieve the load into an existing column and the column removed. The support structure usually needs to be elaborate and massive because the settlement should be kept to a minimum. If footing work is required, the support system needs to be away from the excavation area. Considerations for thermal movements should also be given to the shoring system if large movements are expected. Typically 10% DL lateral capacity is used for the support system in moderate seismic areas. When the column is demolished, care must be taken so as not to damage the existing main longitudinal bars so they can be used. At least a good lap distance should be left for these bars as they stub out from the bent cap. Extra dowels into the cap can be added. After the footings work is complete and the main longitudinal steel is in place, the horizontal ties can be added to the column steel. The column form-work is then buttoned up and concrete pumped to the top of the column. The form-work should be grout tight and means provided to vibrate the concrete.

Sometimes passageways are cored at an angle through the bent cap to allow for the concrete placement but this damages some reinforcement.

Another retrofit measure for side by side structures is to tie the two bridges together by removing the edge of deck leaving the bars exposed, and pouring a new deck that locks the structures together. A new column and footing can be placed at the bents in-between the two structures and tied into a new cap and deck thus increasing both structure's capacity.

Stone Columns and Grout Injection

If a bridge site is placed in soft sands and liquefaction of the soil is a probability, stone columns or grout injection can be used.

Stone columns are large rocks placed in drilled holes around the foundation that prevent water pore pressure from building up in the local area. Large diameter holes are drilled around the foundation and rocks are packed into the holes to create a stone column. In a major event if the water pressure builds up, the column will relieve the pressure and water will spurt up the column, similar to a sand boil.

Grout injection is a series of pressure grouted holes that densify the local areas around foundations to prevent liquefaction.

Conclusion

There are a number of ways to retrofit a bridge structure to prevent collapse. Each method usually has a unique design unto itself. These designs also have a unique style of construction. All the various methods of retrofitting a bridge should be compared and the best method chosen to be the most economical and have a limited amount of impact to the traveling public.