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The Design & Installation of Bridge Strengthening Schemes using Minipiles

This paper describes the design & installation of three bridge strengthening schemes carried out by Keller Colcrete between 1991 & 1994.

The load bearing capacity of the abutments was increased by the installation of high capacity vertical & raking minipiles through brickwork/blockwork abutments, whilst the steel decks were removed for strengthening/refurbishment under factory conditions.

Computer analysis techniques were used to calculate the minipile loadings & also to assess the structural capacity of the minipile cross-section.

The main advantages of this type of bridge strengthening are listed below :

(i) Minimal disruption (compared to "new-build").
(ii) Minimal programme period (compared to "new-build").
(iii) Minimal cost (compared to "new-build")
(iv) The original bridge aesthetics are maintained.
(v) The original abutment is strengthened.
(vi) Intimate contact between the abutment & the underlying founding strata is obtained (including bedrock penetration if required).

INTRODUCTION

With the ever increasing weight & volume of traffic on our highways many of the bridges that they pass over will need upgrading or replacing at some time in the future. This is especially true of the older bridges constructed around the turn of the century, which may also be approaching the end of their design life.

One option is to upgrade the existing abutments using rotary bored minipiles & remove the deck for refurbishment under factory conditions.

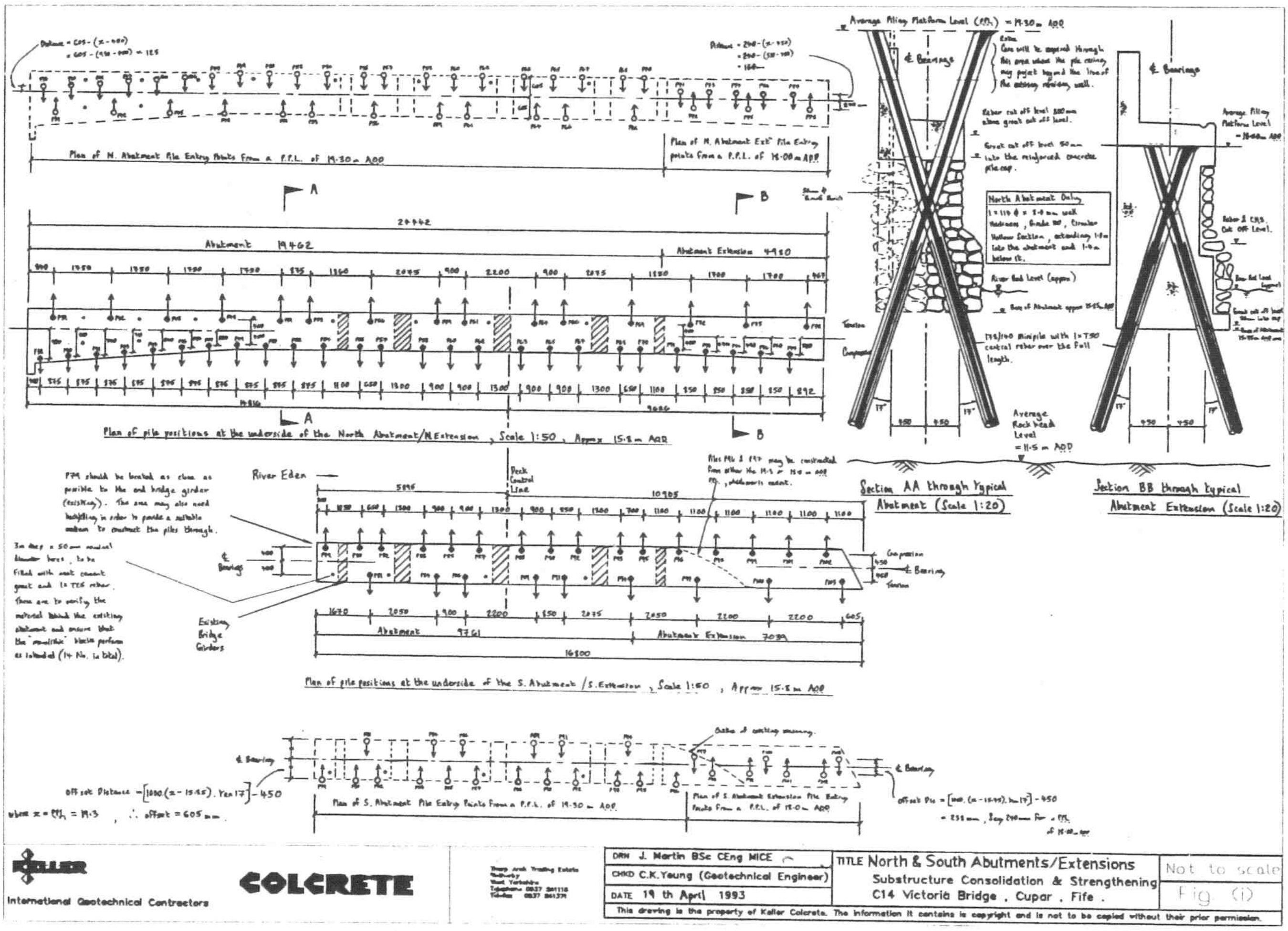
This paper discusses three such projects carried out at the following locations:

(i) Victoria Bridge, Cupar, Fife.
(ii) Hacken Bridge, Bolton.
(iii) Calder Grange Bridge, Knottingley.

The minipile designs were carried out using the "PIGLET" Pile Group Analysis computer program to calculate the potential axial forces, bending moments, & displacements within the minipiles. From the "PIGLET" analyses the maximum potential bending moment occurred at the base of the abutment. To safely accommodate these relatively high bending moments an additional steel circular hollow section was carefully located over the critical length. The elastic analysis of the composite minipile cross-section to determine the ultimate bending moment capacity was carried out using the Oasys "ADSEC" computer program.

DESIGN

All three designs were carried out generally in accordance with B.S.5400, B.S.8004, B.S.8081 & B.S.8110. However, B.S.8004 has not been drafted on the basis of limit state design & therefore all



nominal loads were adopted as design loads (taking $\gamma_{fL} = 1.0$ & $\gamma_{f3} = 1.0$) as recommended in B.S.5400 and an overall factor of safety applied to the pile design.

The critical loading for each section was assessed using standard methods, taking into account all the necessary combinations of earth pressures plus dead, live & impact loadings. To illustrate the method the North Abutment Section at Victoria Bridge, Cupar will be used, see fig. (i). A unit length is considered & all of the critical design loadings are combined into a single horizontal force, vertical force & bending moment about the centre of gravity of the abutment base, see fig. (ii). The bearing capacity of the existing foundations is totally ignored, i.e. it is assumed that the design loadings are taken by the minipiles alone (conservative).

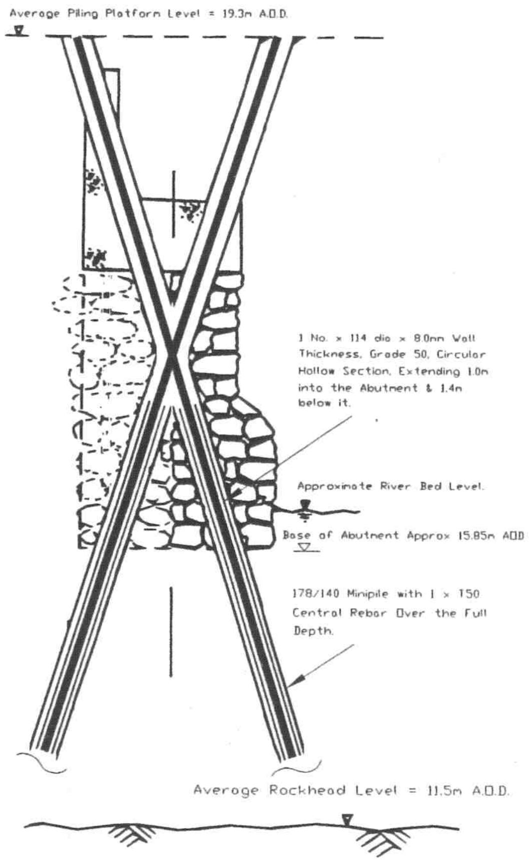
The ground conditions at Cupar consisted of approx. 3.0m of blockwork abutment over approx. 5.0m of medium dense gravel ($\overline{N}$=15) over moderately strong conglomerate bedrock (U.C.S.>20 MN/m²).

The "Piglet" computer program is then used to analyse the load deformation response of the pile group (elastic analysis). The positions & angles of the minipiles can be varied to give the optimum results. The program requires the shear modulus "G" (MN/m²), which without other information is normally approximated from "300 x Cu" for cohesive soil or from "1000 N" for granular material. In our calculations we used G=15,000 MN/m² at the base of the abutment, rising to G=100,000 MN/m² in the bedrock. An assessment of the equivalent Young's Modulus of the minipiles is also calculated from the relative percentages of grout & steel as follows :

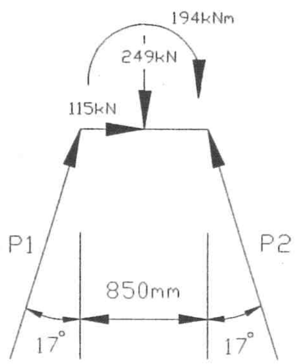
$$E_{pile} = (0.16\ \% \times 200{,}000) + (0.84\ \% \times 27{,}500)$$

$$= 55{,}400\ \text{MN/m}^2$$

The pile head is assumed to be "fully fixed" into the abutment, i.e. it has a high rotational stiffness where it is bonded into the blockwork. A value of 0.25 is used for Poisson's Ratio for all types of loading - axial, lateral or torsional. The results of the "Piglet" analysis are given in fig.(iii).



Section A A Through Typical Abutment



Critical Loadings Per Metre of Abutment at the Centre of Gravity of the Base

Fig (ii) Victoria Bridge, Cupar, Fife.

By inspection of the "Piglet" analysis results the following ultimate design loadings are obtained :

Ultimate Tensile Pile Loading Per Unit Length = - 81 KN

Ultimate Compression Pile Loading Per Unit Length = + 337 KN

Ultimate Bending Moment Per Unit Length = 14.6 KNm.

Output from Pile Group Analysis Program - PIGLET

Victoria Bridge, Cupar, Fife.

Load case no. 1 out of 1

Pile loads and deformations

Vertical load	Horizontal load (x)	Moment (x to z)
2.4900E+02	1.1500E+02	1.9400E+02
Vertical deflection	**Horizontal defn (x)**	**Rotation (x to z)**
7.8549E-04	8.5119E-04	2.1067E-03

Pile no,	Axial loads	Lateral loads (x)	Moments (x to z)
1	-8.0919E+01	2.6513E+00	8.6786E+00
2	3.3687E+02	-1.3486E+01	1.4560E+01

Output from Pile Group Analysis Program - PIGLET Version dated January, 1992

Victoria Bridge, Cupar, Fife.

Load case no. 1 out of 1

Profiles of bending moments in the (x,z) plane and (optionally) lateral deflections (relative to soil) in the x direction for specified 2 piles

Pile number 1

Depth	0.00E+00	2.32E-01	4.65E-01	6.97E-01	9.30E-01	1.16E+00	1.39E+00	1.63E+00
Moment	8.68E+00	7.82E+00	6.30E+00	4.50E+00	2.77E+00	1.44E+00	5.76E-01	1.51E-01
Defn u	8.87E-04	4.72E-04	1.97E-04	3.81E-05	-3.08E-05	-5.06E-05	-3.63E-05	-1.24E-05

Pile number 2

Depth	0.00E+00	2.32E-01	4.65E-01	6.97E-01	9.30E-01	1.16E+00	1.39E+00	1.63E+00
Moment	1.46E+01	1.05E+01	7.02E+00	4.15E+00	2.04E+00	4.53E-01	-3.38E-01	-3.98E-01
Defn u	2.67E-04	-9.90E-05	-2.77E-04	-3.38E-04	-3.37E-04	-2.38E-04	-1.29E-04	-3.79E-05

Fig (iii) "Piglet" Pile Group Analysis Results

To accommodate these ultimate loadings the following pile spacings are proposed :

Compression Piles at 1.1m centres (ave) - Ult. Pile Loading = +371KN

Tension Piles at 2.2m centres (ave) - Ult. Pile Loading = - 178 KN

Therefore, the ultimate bending moment = 2.2 x 8.7 = 19.1 KNm.

It can be seen from the "Piglet" analysis that the ultimate bending moment only occurs over a short distance below the base of the abutment. To allow for this area of potentially high bending moment an extra 2.5m x 114mm dia x 6.3mm wall thickness circular hollow section (C.H.S.) will be installed. This is in addition to the full length T50 rebar connected together with full strength couplers. The C.H.S. is accurately centralised & located using specially designed securing brackets at each end.

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Victoria Bridge, Cupar.                                  Job No.  9640
185mm Minipile with 1xT50 & 114x6.3 CHS                  Made by  JM
                                                         Date     26-Apr-95
                              Ref:9640          (1)      Checked

Oasys ADSEC Version 2.0                                  (c) Oasys Ltd. 1992
Concrete section analysis
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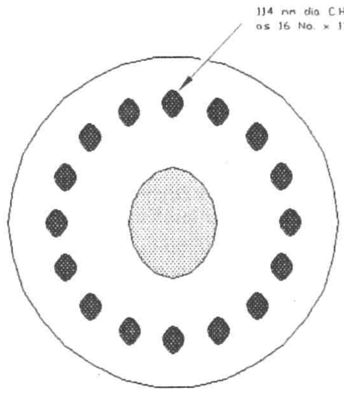


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Victoria Bridge, Cupar.                                  Job No.  9640
185mm Minipile with 1xT50 & 114x6.3 CHS                  Made by  JM
                                                         Date     26-Apr-95
                              Ref:9640          (5)      Checked

Oasys ADSEC Version 2.0                                  (c) Oasys Ltd. 1992
Concrete section analysis
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ULTIMATE N-M PLOT Moment angle: 0

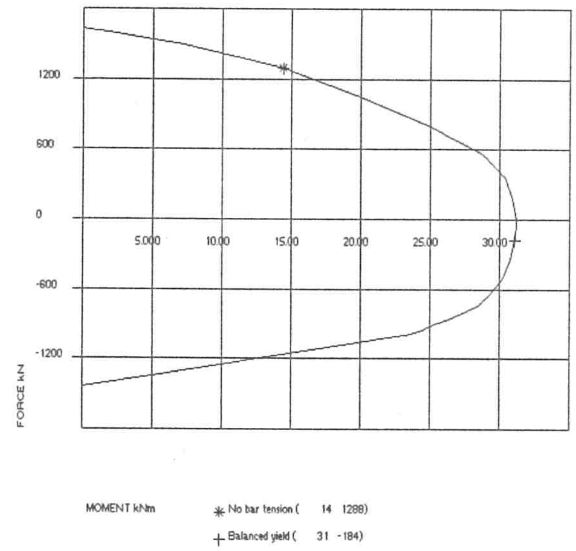

Fig (iv) "ADSEC" Analysis Results (B.M.Capacity)

The analysis of the bending moment capacity of the minipile cross-section is carried out using the Oasys "ADSEC" computer program. These analyses gave an ultimate bending moment capacity of 7.5 KNm for the minipile with a single T50 rebar & 30.0 KNm with the additional C.H.S., see fig. (iv). Therefore, the minimum load factor over the critical length is 30/19.1 = 1.57 which is acceptable. The design bending moment diminishes rapidly with depth beneath the abutment & is less than 1 KNm at 1.4m below the pile head.

The next stage is to design the required rock socket length. This was based on the point load tests from the site investigation report which indicated uniaxial compressive strengths (U.C.S.) of 20 to 25 N/mm². B.S.8081, Table 25, recommends an ultimate bond of 10% of the U.C.S.,

i.e. $\tau_u = 2.25$ N/mm²

We propose to use a 3.0m deep x 0.14m diameter rock socket & ignore any end-bearing component (conservative).

$$\text{Therefore, } \tau_w = \frac{371{,}000}{(\pi \times 140 \times 3{,}000)} = 0.281 \text{ N/mm}^2$$

This gives a factor of safety of 8.0 which is greater than required but allows for any variances in the bedrock.

The bond stress into the abutment is also checked & where necessary, additional 200mm x 200mm x 20mm thick steel plates are securely bolted to the T50 rebar & cast into the reinforced concrete capping beam. This is particularly important for the tension piles.

A preliminary static pile test was carried out to 2.5 x S.W.L. to verify the axial capacity of the pile. In order to remove the need for substantial kentledge in a restricted site, 4 No. tension piles were used to provide the necessary reactive force. The preliminary test pile results are shown in fig (v)

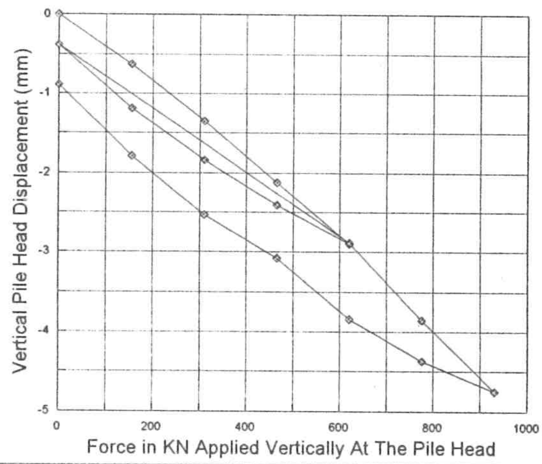

Fig (v) Preliminary Pile Test Results, Victoria Bridge, Cupar, Fife.

The designs for Hacken Bridge & Calder Grange Bridge were carried out in a very similar manner. However, it was possible to achieve the required bending moment capacity over the critical section by using cages, thus reducing costs (6 x T20 x 2.5m long inside a 150mm dia R6 helix). Furthermore, the Hacken Bridge design accommodated the design forces with vertical minipiles which are simpler to install & in some respects strengthens the abutment to a greater extent.

INSTALLATION

A total of 103 No. x 178mm/140mm ϕ minipiles were installed at Victoria Bridge, Cupar, Fife. The piles are installed using hymac based drill rigs incorporating water flush rotary percussive duplex drilling techniques. The 178mm ϕ temporary casing is advanced through the abutment & underlying sands/gravels & sealed into the top of the conglomerate bedrock. A minimum 3.0m deep x 140mm ϕ open hole rock socket is then formed, giving an average minipile length of 10.0m. The mast inclination is set using an inclinometer.

Upon completion of boring to the required depth the drill string is removed & the pile shaft cast in a high strength fluid grout composed of the following:

50 kg of Sulphate Resisting Cement
50 kg of Sharp Concreting Sand
22.5 lt of Potable Water

The grout is mixed in a proprietary Colcrete colloidal mixer & pumped into the base of the pile bore through a small diameter plastic tremmie pipe. The colloidal mixer is a high shear mixer which "wets" between 70 & 80% of the cement particles compared to 30 to 40% for the more conventional paddle mixer (N.B. 50kg of cement has a total surface area of around 17km^2). The characteristic strength of the mix is 40N/mm^2 at 28 days, however strengths of between 50 & 70N/mm^2 are normally obtained. Grouting is continued until good quality (fresh) grout is obtained at the top of the bore. Three cubes are taken during the grouting of each pile for crushing at 7 & 28 days with 1 No. spare.

After completion of the initial grouting the tremmie pipe is removed & the reinforcement is inserted in approx. 3 to 4m lengths. The rebar is connected together with full strength couplers & is centralized with P.V.C. coated lantern spacers at approx. 1.5m centres. The 2.5m length of C.H.S. is accurately centralized/located during the installation of the full depth T50 rebar using specially designed brackets. Finally, the temporary casing is carefully removed whilst keeping the grout level continually topped up to platform level. Due to the fluid nature of the grout mix the "grout take" is generally of the order of twice the theoretical volume due to permeation into the granular strata & abutment voids. Photographs of the minipiling works are given in figures (vi) & (vii).

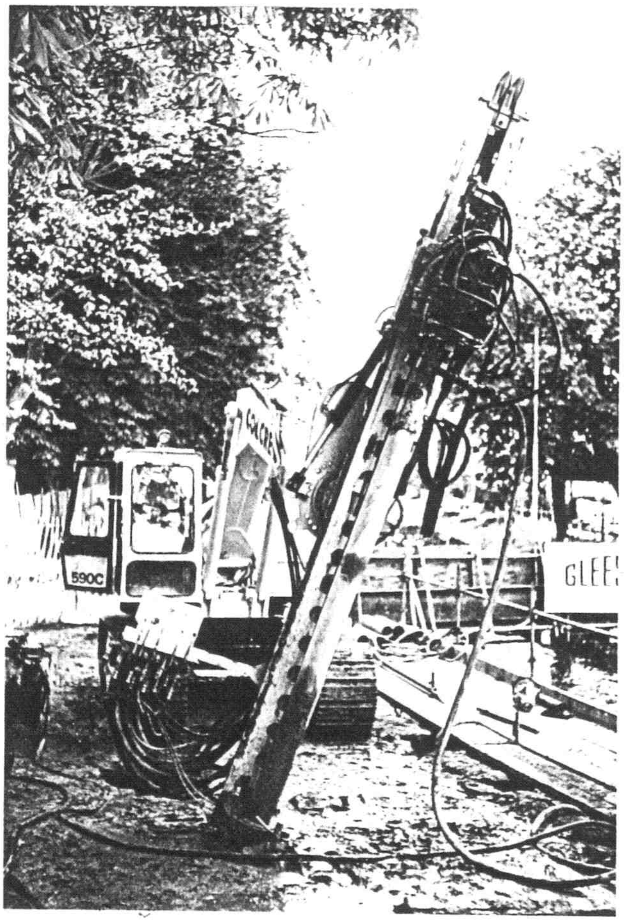

Fig (vi) Drilling of Raking Tension Pile

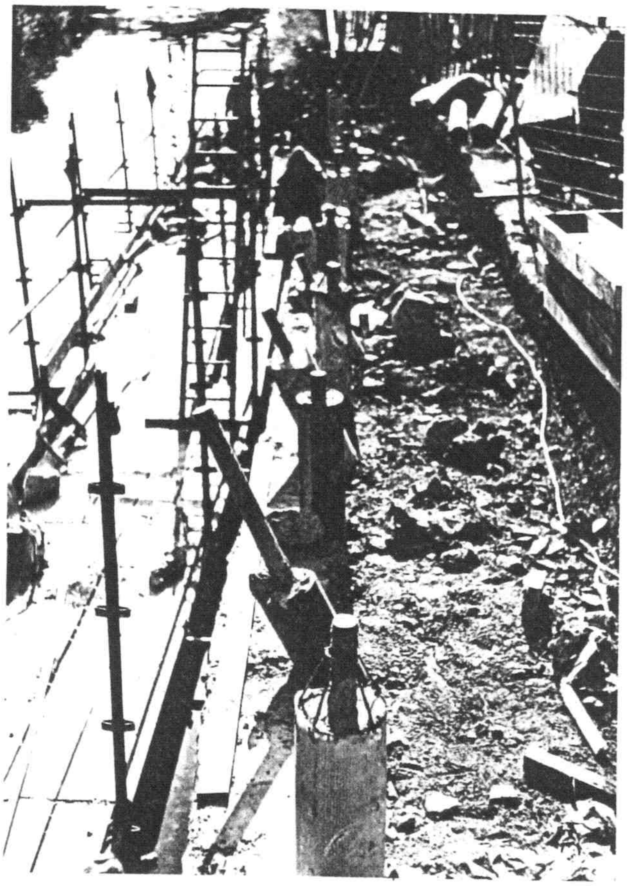

Fig (vii) Completed Minipiles along Waterend Road Retaining Wall.

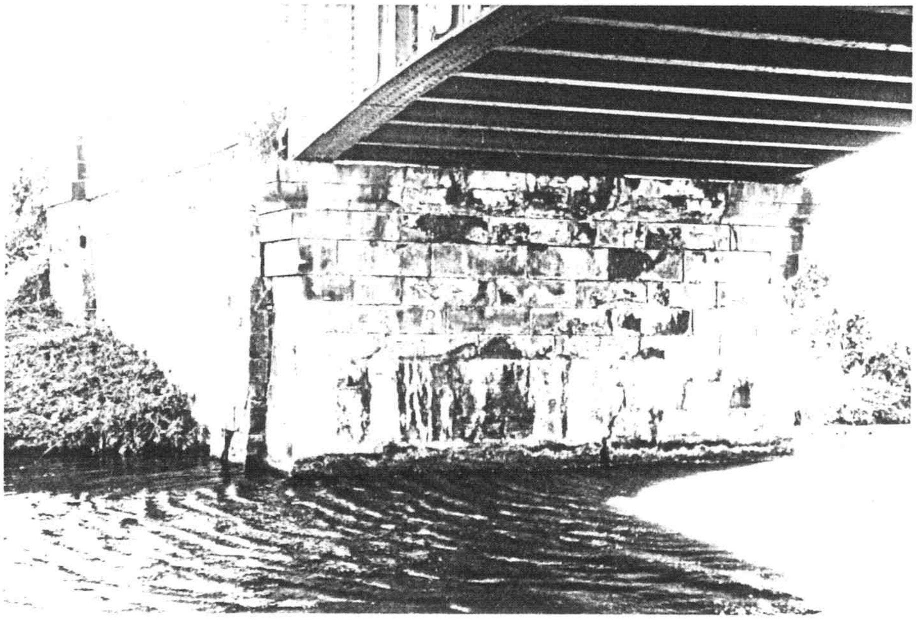

Fig (viii) Large Vertical Crack in the
Southern Abutment Prior to Minipiling Works.
Calder Grange Bridge, Knottingley.

A total of 31 No. x 220/200mm diameter rotary bored minipiles were installed through the north & south abutments of Calder Grange Bridge, Knottingley. The original structure was showing signs of distress due to the undermining of the abutments. The erosion has been caused by the frequent passage of large coal barges travelling between Knottingley Pit & the nearby Ferrybridge Power Station. A large vertical crack at the centre of the southern abutment can clearly be seen in fig. (viii). Prior to commencement of the minipiling works these cracks & undermined areas had to be repaired by divers using proprietary materials.

The minipiles were bored through the following strata using rock roller water flushed rotary duplex drilling techniques with temporary casing as required:

0.0m → 6.5m	Abutment.
6.5m → 10.0m	Soft/Firm Silty Clay.
10.0m → 17.5m	Dense Sand & Gravel.
17.5m → Onwards	Very Stiff Silty Clay.

Keller Colcrete installed 18 No. x +567KN S.W.L. compression piles x 21.0m deep & 13 No. x -339KN S.W.L. tension piles x 16.5m deep. The piles are all inclined at 9° to the vertical & contain 1 No. x central T40 rebar extending to the full depth. An additional 2.5m long reinforcement cage consisting of (6 x T16) inside a 150mm ϕ x R6 helix was installed 1.0m into the base of the abutment & 1.5m below it.

Preliminary static tension & compression pile tests were carried out to confirm the adequacy of the pile lengths.

A total of 42 No. x 12.0m deep minipiles were installed through the east & west abutments of Hacken Bridge, Near Bolton. The underlying ground comprised of coal measures strata & the drilling was undertaken using purely rotary techniques. The lateral forces & bending moments were less than at Cupar & Knottingley & it was possible to design the scheme using vertical minipiles. Evenly spaced vertical minipiles provide a more uniform method of strengthening the abutment. Alternately raking minipiles have an inherently weak horizontal plane mid-way down the abutment where the minipiles cross over. A crane was available on this site which allowed the (6 x T20) cages to be made from 12.0m long stock lengths of steel & lifted into the pile bores in single lengths. Fig. (iv) shows the drilling operations with a view over the River Croal in the background. The bridge deck had been completely removed prior to our arrival on site.

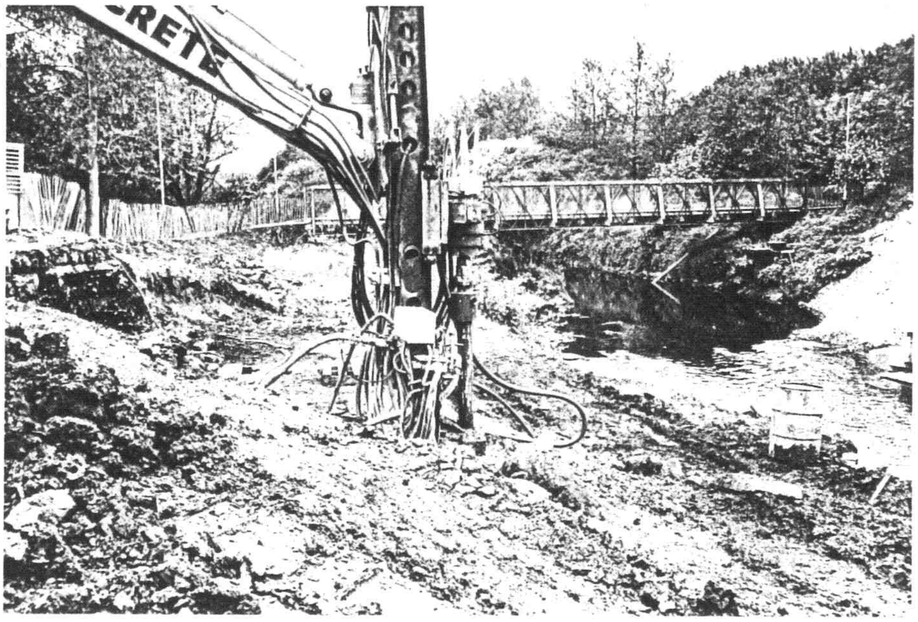

Fig (iv) Drilling of Minipiles.
Hacken Bridge, Bolton.

CONCLUSION

These three contracts have shown that the installation of minipiles into the abutments/piers of existing bridges provides a viable method of upgrading or repairing many existing structures. The main advantages are listed below:

(i) Minimum disruption
(compared to new build).

(ii) Minimum programme period
(compared to new build).

(iii) Minimum cost
(compared to new build).

(iv) The original bridge aethsethics are maintained.

(v) An intimate bond is provided between the existing structure & competent ground at depth.

(vi) The exsisting structure is internally strenghtened by the high strength fluid grout & the high tensile steel reinforcement.

REFERENCES

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