Kwinana Freeway Bridge Abutments – Value Adding Through Innovation and Partnering

Mr Doug Jenkins, Principal, Interactive Design Services.
Chris Lawson, Engineering Manager, Reinforced Earth Pty Ltd.

Synopsis:

The abutments for Perth's Kwinana Freeway extension bridges are believed to be a World's first, in the combination of integrated Reinforced Earth abutments with full height pre-cast facing panels. This combination allowed bridge spans to be minimized whilst maintaining simple and rapid erection procedures and a high quality finish matching in-situ structures on earlier sections of the Freeway.

The original concept was developed for Thiess Contractors by the project designers Breuchle Gilchrist & Evans. The Reinforced Earth Company successfully tendered for the supply contract with a revised design providing further savings in cost and ease of construction. The final design required detailed consideration of the interaction of construction and bridge loading on the facing panels and the reinforced soil abutment as a whole. The process was brought to a successful conclusion through cooperation between the three parties involved.

This paper describes the design and construction of this project and considers the advantages and limitations of this form of construction.

1. Introduction

The Kwinana Freeway, stretching south from Perth to Kwinana, WA, is being extended by 11 kilometres to Safety Bay (Figure 1). The project includes 12 new grade separated interchanges, which are the subject of this paper. The contract for design and construction of the freeway was awarded to Thiess Contractors in early 2000. Thiess subsequently appointed Bruechle Gilchrist & Evans (BG&E) to design the bridges for the project. BG&E developed an innovative abutment design combining reinforced soil abutments with full height precast concrete facing panels and integrated bridge supports. In tendering for the abutment supply contract Reinforced Earth developed the design to incorporate their proprietary soil reinforcement products, and to further improve efficiency and constructability. Reinforced Earth were awarded the contract for detailed design and supply of the bridge abutments in March 2000. The final design was developed in close cooperation with Thiess and BG&E, allowing the project requirements to be met in a very tight time frame.

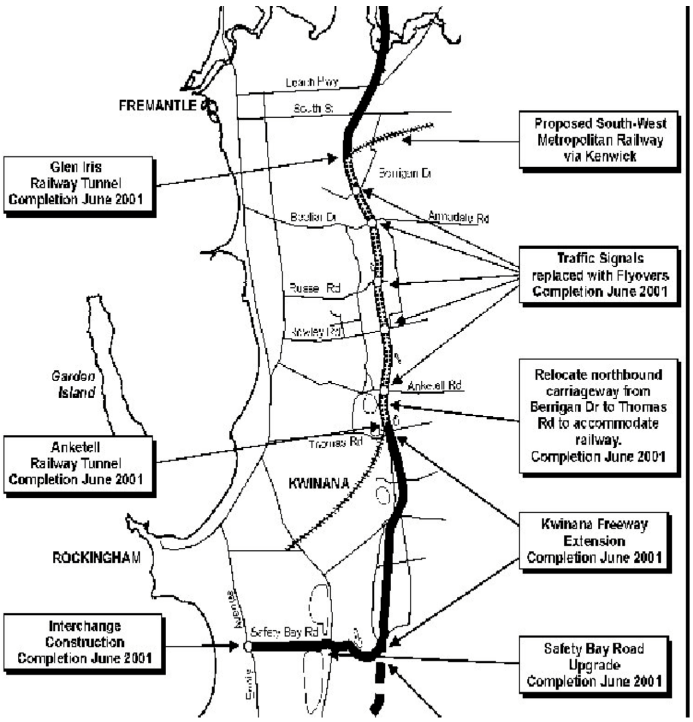


Figure 1. Kwinana Freeway Locality Plan

2. Client Requirements

A typical layout of one of the freeway bridges is shown in Figure 2. The design brief included the following requirements:

Twin span bridges crossing the two lane freeway and to accommodate the future South West Metropolitan Railway (SWMR)

Bridge abutments and wing walls to be consistent with the treatment of the existing freeway bridges

Construction techniques to allow rapid construction with high quality surface finishes.

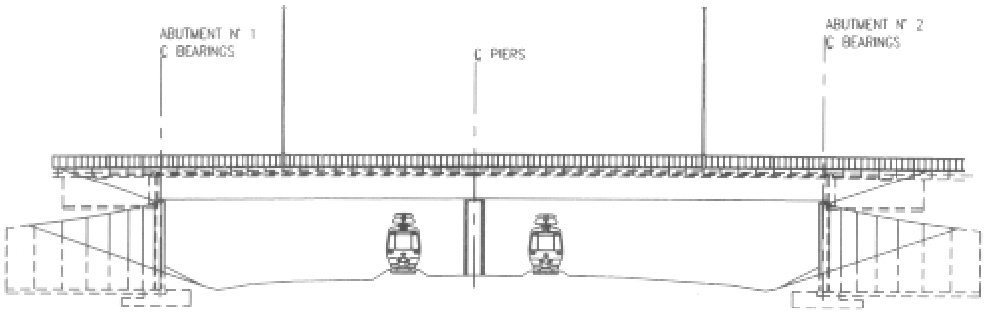


Figure 2. Typical Elevation

3. The BG&E Proposal

A cross section of the abutment facing design proposed by BG&E is shown in Figure 3. The main features of the design were:

Vertical loads from the bridge deck are transferred to the foundations through supports integral with the facing panels, allowing the bridge span to be minimised.

The support panels incorporated two cylindrical voids, as forms for the deck support columns

The deck support columns were supported on large spread footings, which also supported the intermediate abutment facing panels.

Horizontal loads from the bridge deck and soil loads were taken by a reinforced soil system using flat galvanised steel strip reinforcing elements.

The wing wall facing panels were similar to the abutment intermediate panels, except that the front face was curved to allow the wing walls to be constructed to a smooth circular alignment, without steps at the panel joints.

The wing wall panels were provided with small levelling pads to support the panel weight during construction, with the majority of the wall weight being supported by the reinforced soil mass, as in a conventional reinforced soil wall.

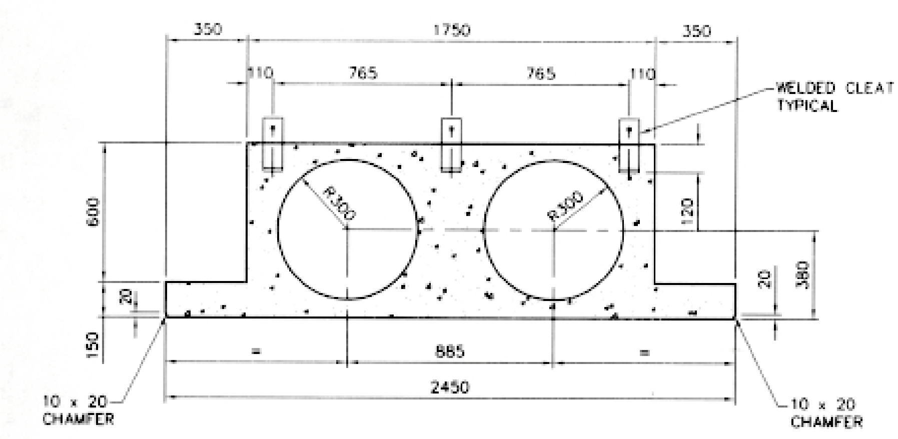


Figure 3. BG&E Abutment Facing

4. The Reinforced Earth Design

A typical cross section of the wall design finally provided by The Reinforced Earth Company is shown in figure 4. The main changes from the original design were:

- The large deck support panels, with integrated column formers, were replaced with flat panels with two separate precast channels to form the deck support columns. This allowed a reduction in the volume of precast concrete, and a substantial reduction in the maximum panel weight (Figure 5).
- Wing wall panels incorporating a 20m radius curvature.
- Reinforced Earth proprietary soil reinforcing strip was used. This is a ribbed galvanised steel strip, providing significantly higher soil interface friction than flat steel strip.
- The spacing of the soil reinforcement was revised to suit the new system.
- The in-situ concrete elements (the deck support columns and headstock) were re-designed to suit the revised cross section dimensions.

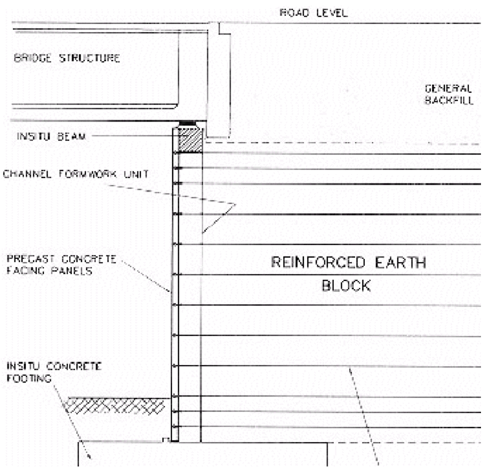


Figure 4. Typical Abutment X-Section

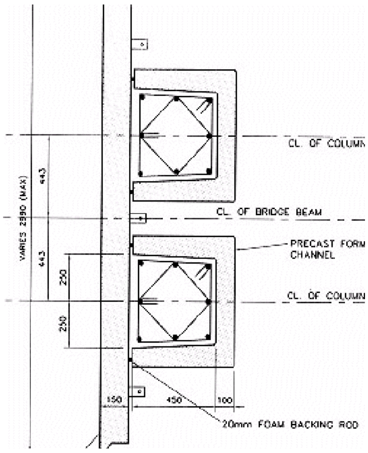


Figure 5. Panel and Column Support

5. The Tender Process

The design and construct contract is becoming increasingly popular, and undoubtedly has advantages in generating tenders that optimise design efficiency in terms of both supply of materials and construction costs. This form of contract does have a number of potential disadvantages however:

- The focus on cost may be to the detriment of the quality of the project.
- The time allowed for design in the tender period is much shorter than would normally be allowed in contracts where responsibility for design and construction are separated.
- Decisions taken at the project tender stage may preclude the introduction of innovative design processes and specialist techniques at the final design stage.
- Lack of time, and the requirement for tender confidentiality, may reduce the effectiveness of specialist suppliers in providing design advice and assistance.
- Since the contractor is taking the risk for the cost of the design, familiar and proven construction techniques may be preferred to new techniques.

In spite of these factors, in the case of the Kwinana Freeway abutments an innovative and efficient alternative design was provided, that satisfied the requirements of both the owner and the contractor. The successful implementation of design innovation on this project was aided by:

- A project brief with clearly stated requirements for the quality and appearance of the finished product.
- The willingness of the contractor to consider and adopt innovative design solutions.
- A tender process allowing suppliers time to develop design alternatives.
- A cooperative approach between the bridge designer and the wall system supplier.

The tender package for the abutment walls included details of the wall panel design by BG&E. During the tender period Reinforced Earth developed two alternative designs:

- A design using discrete rectangular panels, based on the standard Reinforced Earth system.
- A design using full height panels with integrated abutments, similar in concept to the BG&E design.

No Reinforced Earth structures incorporating both full height panels and integrated abutments had previously been constructed. Because this form of construction does not posses the flexibility shown by the standard Reinforced Earth system it was important to verify that the system would behave as intended both during and after construction. During the tender period the design and the construction procedures had to be developed to a sufficient level to be confident of satisfactory behaviour:

Overseas Reinforced Earth companies with experience of aspects of the design were contacted. Retaining walls using full height panels of a similar size had been constructed in the USA, and integrated abutments using discrete panels had been used in Spain. These companies provided typical design calculations, construction drawings, and advice on construction procedures.

A detailed analysis was carried out of the stresses in the wall panels and the soil reinforcement during transport, erection and backfilling.

The effect of consolidation of the foundation and the backfill on the structure was analysed.

The design of the revised deck support columns was checked for vertical and horizontal loads, taking account of the interaction between the columns and the backfill.

During the tender negotiations it became clear that the full height panel system better suited the requirements of the contractor and the owner, and that the foundations and backfill properties were suitable for this form of construction. The design was progressively developed during the tender period in conjunction with Thiess and BG&E. The supply contract was finally let to Reinforced Earth in March 2000. Contract requirements included:

Reinforced Earth to take full responsibility for the design and approval of the abutments and wing walls, including the deck support columns.

Detailed designs to be prepared on a fast track basis as information became available.

Delivery of precast panels and channels to suit the contractor's programme.

Design of lifting, transport, and handling systems.

Provision of on site construction advice.

6. Previous Examples Of Full Height Panels And Integrated Abutments

Full height panel retaining walls have been used on a number of projects in the USA. They have typically been used on large projects where the large panel size allows fast and efficient erection. Although the system is popular with contractors it's use has been restricted because of the need for good foundations, not subject to significant differential settlement.

Reinforced Earth had developed the concept of integrated abutments in the 1980's. In this system the deck support columns are built into wall facing panels; a number of projects of this type have been constructed in Spain (Figure 6). The deck support columns have been formed both by circular voids in special panels, and by precast channels placed against the back of standard panels.

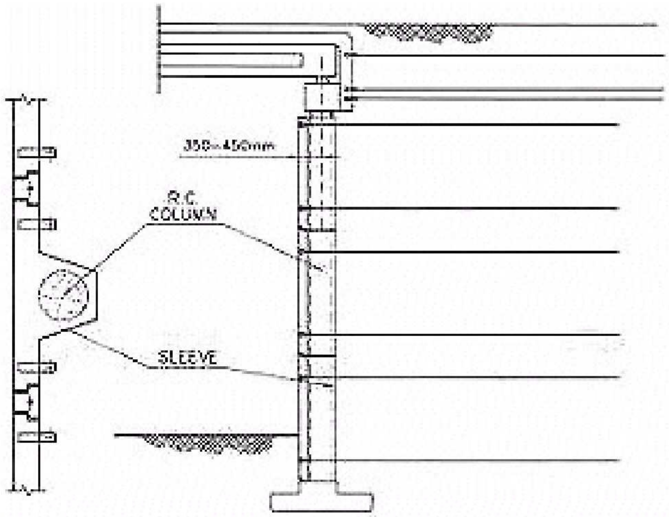


Figure 6. Integrated Abutment Facing developed by Terra Armada.

7. Design For Construction And Final Loads

In a conventional Reinforced Earth wall the flexibility of the relatively small facing panels allows loads to re-distribute during construction, and vertical settlement can be accommodated by opening and closing of the joints. Horizontal deflections occurring during construction can be adjusted as work proceeds by giving each panel a small preset inclination The use of full height panels introduces several potential problems:

The panel, soil reinforcement, erection props, and backfill form a redundant system, which may cause stress concentrations, with potential for cracking of the panels or yield or slip of the reinforcement.

Panels must be pre-set at the start of construction, to allow for rotation about the base as back-fill proceeds.

The system has limited capacity to accept differential settlement, and should only be used on uniform foundations with predictable settlement.

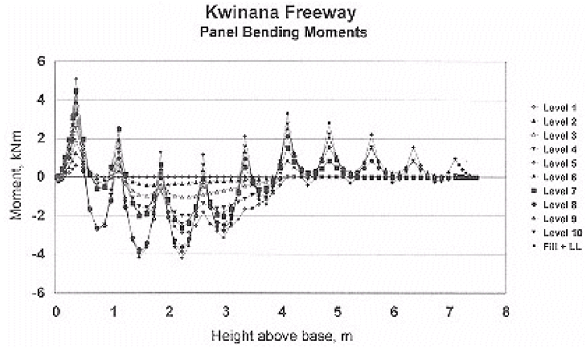
The construction load analysis was carried out using the finite element package Strand7. The wall, props, and soil reinforcement were modelled using 2D beam elements. The main features of the analysis were:

The soil load, and restraint from the soil reinforcement, were added in stages, to model the actual sequence of construction.

During construction the props supporting the facing the panels were wound back slightly as filling progressed, and were removed when the fill reached the height of the prop head. This sequence was modelled in the analysis.

Upper and lower bound values were used for the stiffness of the concrete facing panels, and the soil reinforcement, to find the most severe loading on both the concrete and the reinforcing strips.

The strand7 analysis was also used for the internal design under in-service loads. The external stability was checked using conventional Reinforced Earth design programmes.



A separate analysis was carried out for the design of the deck support columns and headstocks. The design loads consisted of:

Vertical bearing loads with variable eccentricity, to allow for bearing movement and variations in the panel deflection during backfill. The specified live load was the new SM1600 load.

Transverse loads as specified by the Austroads Bridge Design Code.

Longitudinal loads due to bearing shear.

Transverse deck loads were resolved in the direction of the abutment, resulting in high longitudinal loads in some high skew bridges.

A 3D frame analysis was carried out on the complete abutment system, including deck support columns, facing panels, and soil reinforcement. Upper and lower bound stiffness values were again used to find the most severe loading on each element.

Typical output from the analyses is shown in Figures 7 and 8.

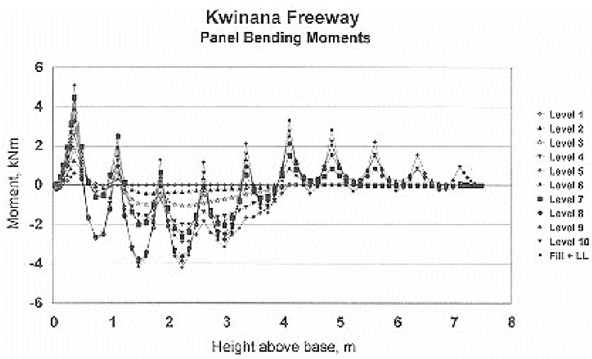


Figure 7. 2D Analysis results

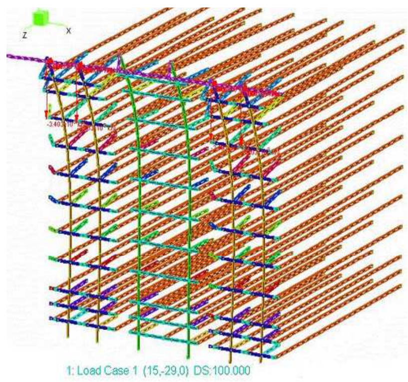


Figure 8. 3D Analysis output
Deflection x 100

8. Design For Transport And Erection

Design of the lifting, transport, and erection support systems was comparatively straight forward, but required careful analysis and detailing to ensure safe working practices, and to avoid cracking of the large slender panels. Reid Construction Systems provided the lifting and support hardware, designed the transport and erection systems, and reviewed the lifting systems.

Due to variation in the spacing of the bridge bearings and in the height of the panels there were a large number of different panel sizes, with different reinforcing strip arrangements. It was decided to produce a separate fabrication drawing for every panel, indicating panel dimensions, reinforcement locations, and lifting and propping point locations. The large drafting effort involved proved to be a worthwhile investment in minimising lost production due to precasting errors.

9. Precasting, Storage and Delivery

The precasting sub-contract was awarded to Ultrafloor. Steel moulds were fabricated to accommodate the maximum width and height of panel, with adjustable top and side forms (see Figure 9). A total of 5 panel forms, and 2 channel forms were used, working on a 24 hour cycle. The forms were covered after casting to achieve the required lifting strength of 15 MPa.

Accuracy in the placement of support points was important, to prevent cracking of the large panels during storage and delivery. Supports and shims were placed with a surveyor's level to ensure accurate location in line and level. Figure 10 shows the support arrangement for the panels during transport to site.

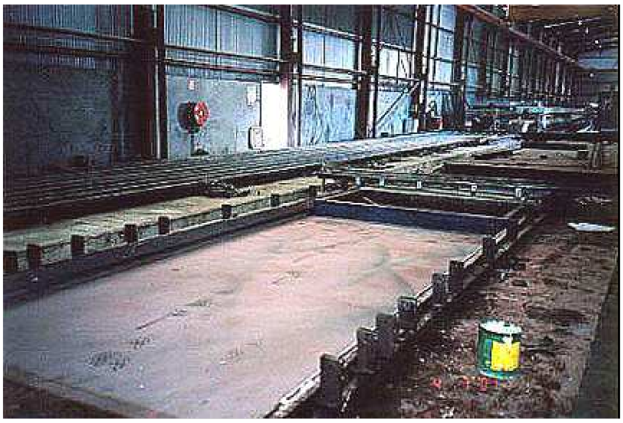


Figure 9. Adjustable Steel Mould

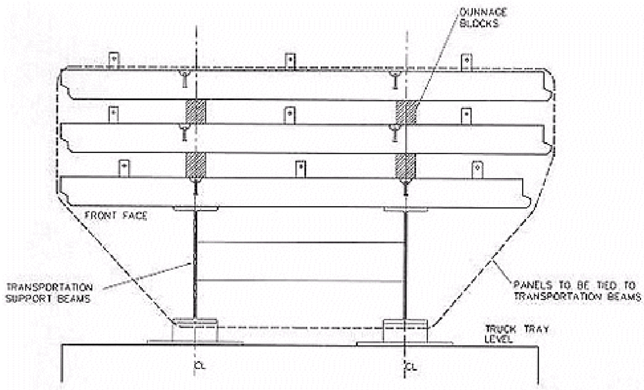


Figure 10. Panel Transportation Detail

10. Construction

Erection of the facing panels, column reinforcement and precast channels for each bridge was typically completed in three to four days. A typical day's production saw 15 wall panels erected and propped in position (See Figure 11). After reinforcement positioned, the deck support channels were placed and temporarily clamped to the panels at the prop level located approximately 4 metres above base level (See Figure 12). Erection was completed with the placement of geotextile over the vertical joints.

Backfilling was completed over a period of about two weeks for each abutment. A work crew consisting of a loader, bobcat, roller, and three labourers with plate compactors placed the fill in 375 mm lifts (maximum). After each lift the props were wound back slightly to ensure that deflection of the panels occurred evenly throughout the backfill process. When the fill reached the prop height the props were removed, and the clamps to deck support channels were re-located at the top of the wall. The horizontal deflection at the top of the panels were monitored at each abutment, with a uniform 0.5% of the wall height being found satisfactory.

When the fill reached the top of the deck support channels the in-situ concrete to the columns and headstocks was placed, followed by placement of the deck beams. Finally the in-situ deck and end diaphragms were placed, followed by completion of the backfill and the run-on slabs. A completed abutment is shown in Figures 13 and 14.

Figure 11. Panels Erected and temporarily propped in position.

Figure 12. Column reinforcement in position ready for channel forms.

11. Advantages Of Integrated Abutments With Full Height Facing Panels

The use of Reinforced Earth integrated abutments with full height facing panels has a number of advantages, particularly for large projects:

- Bridge spans are minimised, allowing economies in the bridge deck design.
- Inclusion of the deck support in the facing avoids possible conflicts between piles and soil reinforcing strips.
- The use of large panels allows efficiencies in precasting
- Large full height panels allow rapid erection
- Full height panels may be preferred for architectural reasons

12. Restrictions And Requirements For Successful Implementation

The successful use of full height panels requires a suitable project and site, and imposes a number of restrictions:

Due to the lack of flexibility of full height panels it is essential that foundations are uniform so that differential settlement will be limited. In the case of the Kwinana Freeway a different system was used at one site because of poor foundations.

Settlement and displacement of the soil mass during backfilling has the potential to induce large stresses in full height facing panels. It is therefore essential that good quality granular fill is used, with well controlled placement and compaction. The use of geosynthetic reinforcement is not recommended, because its lower stiffness will result in higher bending stresses in the facing.

Full height panels must be propped from the front until such time as the panels are self supporting. Site restrictions may make this impractical in some cases.

The transport and handling of large thin panels requires great care and the use of large cranes.

The design procedure is more complex for full height panels, particularly with integrated abutments.

Figure 13. Completed Abutment wall with SWMR in foreground.

Figure 14. Front View of Completed Abutment

13. Conclusions

The use of integrated abutments with full height facing panels on the Kwinana Freeway bridges was a successful example of design innovation on a design and construct project. The tender and design process allowed the experience and innovative ideas of the contractor, the bridge designer, and the supplier to be combined to provide a design satisfying the requirements of both the owner and the contractor. The use of this type of construction is recommended for consideration on future projects with suitable foundation and site conditions.