Ash Development Association of Australia

STRUCTURAL FILLS AND THE ROLE OF COAL COMBUSTION PRODUCTS

FLY ASH TECHNICAL NOTE NO. 6

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1. INTRODUCTION

Structural fills are engineered materials composed of soil or earth. A foundation or an embankment will have a requirement to achieve a given strength specific to designed load. The soil, which is usually a natural or quarried material such as earth or gravel, is placed by heavy machinery in layers into its final form. The soil is compacted and strength is measured for compliance with the specification. Structural fills may be used in a number of different applications including embankments, bridging layers or in a retaining function. When placed and compacted correctly they can provide stiff soil layers capable of sustaining significant loads over time to support buildings or other structures ([1, 2, 3]).

There are many specifications for structural fills including those published by state road authorities in Australia. Coal combustion products cover a range of materials. These can be broadly classified as follows:

- Furnace Bottom Ash (FBA)
- Fly Ash (FA) conforming to AS 3582.1 Fine, Medium or Coarse grades ([4]), and
- Fly ash not conforming to AS 3582.1 (often termed Run of Station ash or ROS ash)

Coal combustion products (CCPs) such as FA and FBA are widely used as structural fills worldwide. This is because of their consistent and favourable properties for such applications. CCPs are lightweight, easy to compact and have a consistent particle size distribution making for predictable performance in use as structural fills ([1, 5]).

Structural fills are used in many applications. Constructing an embankment in order to raise the existing elevation of a site is one common application. This may be as a means to bridge an area that is prone to flooding. It can also form part of a dam or be used as a means of levelling a sloping site to construct the foundations of a large building. Structural fills may also be used in the construction of earth strap walls where a retaining wall is made of thin interlocking concrete panels with structural infill material behind. The use of earth straps within the structural fill enhances the retaining ability of such walls. Straps are typically mild steel with an appropriate protective coating such as hot dipped galvanising. Long strap life relies on the structural fill to be clean and consistent in order to allow compaction without damaging the straps or their protective coating.

In the instance where a strap is damaged during construction, it may initiate premature corrosion and subsequent failure design allowances provide for a certain proportion of corrosion induced failures. Other important design considerations include avoiding conditions that might create a galvanic cell, which can accelerate corrosion of the straps or their protective coatings.

2. STRUCTURAL FILL COMPONENTS

For structural fills to work adequately, correct site preparation and a complete geotechnical investigation of the existing ground conditions is required. An understanding of the site behaviour is also required to ensure proper interaction of any material won from site with any imported material placed on site. It is also important to characterise the engineering properties of any material being used in the fill so construction of embankments is efficient and the likely insitu properties are more predictable ([1, 5]).

For fill applications, the need to identify material strength, compressibility and any potential for shrink or swell will be most important to ensure the achievement of the required fill properties ([6,7]). How the structural fill material may react to changes in moisture within the ground over time is very important and may influence whether a particular fill is suitable for a particular application.

3. OPTIMISING NATURAL MATERIALS FOR CONSTRUCTION APPLICATION

Construction of embankments has traditionally involved the use of naturally occurring or specifically quarried materials. A range of laboratory tests identify the key properties such that controlled moisture content with adequate placement and compaction techniques will achieve a series of suitably dense layers ([6, 7]). In such cases the success of the embankment performance lies in the consistency of the underlying layers to distribute load without significantly compressing or failing under the increasing pressure of layers placed above. This form of construction has historically performed well over time but relies on consistency of the structural fill to achieve the required insitu performance properties.

The addition of CCPs to structural fills may enhance the ability of the material to bind under optimum conditions of moisture and compaction and improve the load carrying ability of each layer within the embankment. Chapman & George ([8]) found that a small addition of lime could give considerable strength gains to CCPs. This pozzolanic reaction could potentially be used to assist in the binding of other fill materials. Although there are few local examples of structural fills in Australia using CCPs, there are many documented examples of overseas construction available. Chapman & George ([8]) describe the use of up to 8.5 million cubic metres of CCPs for embankment construction in the An-Yan Expressway, which was built in China in the mid 1990's. Figure 1 shows the construction of an earth reinforced wall using FA as the fill material. This was the first structure of this type in Australia to use CCPs.

Recent experience with the use of FA as an embankment material has demonstrated its use as an excellent engineering fill material where its technical performance has been comparable, if not superior, to natural materials in some cases ([8, 9]). In addition, where construction requires the use of structural fills and is within a radius of 100 km of a coal fired power station, there may be significant cost benefits in using CCPs compared to natural materials.

Fig. 1: Fly ash as a Structural Fill - Earth Reinforced Wall - Mt Piper Power Station [9]

4. DESIGN CHARACTERISTICS

The properties shown below show the benefits of using FA (ROS - not necessarily needing to conform to AS 3582.1 [4] specifications) as engineering fill materials [1]. These include its:

- High internal angle of friction (typically >30o)
- Low unit weight (1.2-1.3 t/m^3) compared to natural materials
- Low compressibility
- Low rates of long term settlement in fill applications
- Availability in large volumes
- Environmental benefits of using a non-renewable waste
- Saving the use of natural materials
- Reducing the needs for further ash storage facilities

Australian Standard AS 2758 (Aggregates and Rock for Engineering Purposes) [3, 10] provides detailed methods to determine the Maximum Dry Density (MDD) and Optimum Moisture Content (OMC) of the CCP intended for use. This needs to be considered for the individual components and the combined blends.

Where weak clays or areas of high moisture are present within the existing ground, surcharge loading may be used to "pre-settle" the site. In this case, the placing, compaction and loading of the site with extra soil layers is used to ensure acceptable levels of settlement have concluded before any building or structure is placed on top of the structural fill. If this practice is not adopted, or the fill is not suitable, it is likely that any structure constructed on top of this unconsolidated fill will settle over time and this may lead to unplanned cracking or damage to the structure. Some guidance for addressing such issues is provided in state Road Authority specifications such as RMS Earthworks specification R44 [7]. The required soil loading of the site and time taken to achieve acceptable settlement is based on the weight of the fill and its ability to remove water from the voids due to compression of materials. After placement of the soil surcharge layer(s) there is a period of waiting time to allow settlement of the area to occur such that any future construction will not be compromised.

The lighter bulk density of CCPs when compared to natural fill materials means a lighter loading on the existing sub grades and thus in turn reduces the waiting time required to achieve full settlement of the fill [1]. This often leads to shortened construction times and cost reductions. In addition, the high permeability of CCPs (particularly FBA) can lead to better dissipation of pore water pressures. This is a particular benefit in construction over a moist or swampy sub grade location, compared with other less porous fill materials [1]. The use of CCPs may also have other advantages over natural materials through the use of lime stabilisation. Here the pozzolanic nature of FA can be activated in a lime rich environment. The process involves FA reacting to form secondary cementitious bonds within the fill, which can increase fill strength and stiffness [1]. Of interest also is the structural stability of FBA. Chapman & George [8] found FBA to have a Californian Bearing Ratio (CBR) of 70%. This is very strong compared to many of the structural layers in a pavement, where CBR levels of 30% can be considered as a good material.

5. CONSTRUCTION GUIDELINES

Issues that impact on the construction of an embankment using CCPs include pre-delivery, transportation, placement and compaction, field testing, finishing and dust control, for pre-delivery, the following is noted:

- In many cases, the CCPs available from a power station will be extracted in a dry form and will need to be conditioned with moisture to assist handling and delivery.
- Alternatively a moistened product from an ash storage facility may be available.
- The optimum moisture content of CCPs can be 30% or higher. Hence conditioning for delivery is generally in the range 20% to 30% to minimise airborne dust and loss of fines.

This conditioning will minimise the presence of dust during delivery and tip off and that loss of surface water within the truck is minimised during transportation. Additional requirements are provided in the NSW and Queensland exemptions [11, 12].

CCPs are normally loaded and delivered in conventional haulage vehicles for delivery to site. It is recommended that material is conditioned with moisture to at least 30% prior to load out and covered to avoid airborne dust from the material. A general rule with vehicle covers is that any trip in excess of 15 minutes will require dustproof tarpaulins. This is normal practice for natural material based structural fills.

Moisture conditioned CCPs are easily placed using conventional earthmoving and compaction equipment. Spreading of moisture conditioned CCPs can be performed using either a small dozer or front end loader. Sufficient moisture addition to achieve the required compaction is normally recommended. Generally this level can be about 3% below the optimum moisture content and this should also assist in reducing dust generation during construction. Field trialling with actual blends is also recommended and experience shows that specified compaction (98%) can often be achieved during the placement and movement of the materials without specific roller compaction. When FBA is to be used, consideration should be given to reducing the specified compaction levels. Attempts to exceed 95% relative density can result in breakdown of the structure of the particles and result in a loss of strength.

Compaction can be achieved when the density ratio (Field/ Laboratory) reaches the required percentage. For example a field MDD might be 98% of the MDD achieved in the laboratory - this needs to be verified on site using the desired material blends.

When the required Reduced Level (RL) of the embankment is reached, it is recommended that the finish surface has sufficient cross fall to permit water run-off during rain events. A cross fall of at least 1% is recommended to avoid water ponding at the surface and a subsequent loss of fines. This recommendation is generalised with trialling and involvement with relevant practitioners encouraged to ensure proper field implementation. In order to provide surface protection to the CCPs placed, an outer layer (usually greater than 100 mm) of local or imported material may be added as a capping layer. Additional seeding or grassing of the surface will allow vegetation to take hold and reduce the risk of localised erosion to ensure that the fill remains in place and provides the necessary structural support over time. Areas of exposed CCPs should be limited during construction and water used to minimise dust is recommended. Suitable dust masks/respirators and other Personal Protective Equipment (PPE) should be used by construction workers as required during all processes, including handling, placement, and compaction. Such procedures are typical for placement of natural material based structural fills.

6. REGULATORY CONSIDERATIONS

In most Australian jurisdictions, CCPs, in particular FA have historically been listed as scheduled wastes and potentially subject to regulation([11]). The Ash Development Association of Australia (ADAA) has undertaken an extensive testing programme on behalf of its members since the 1990s. As a result of this testing it has negotiated various exemptions from regulation and approvals for the beneficial use of FA or FBA in a range of specific applications. In NSW and Queensland in particular, exemptions provide for the use of FA or FBA in structural fills ([12, 13]). In Queensland, FBA is not a regulated waste. Updated information on current regulations applying to CCPs can be obtained from the ADAA.

The use of FA and FBA in structural fills and civil works applications can deliver significant environmental benefits. The appropriate use of CCPs as a resource contributes to sustainable development as it results in a saving of natural resources. CCPs nevertheless do contain trace elements which are present in coal and subsequently also occur naturally in the environment. Many of those trace elements are essential for life, but at higher concentrations may possibly give rise to detrimental impacts as well. Understanding the leaching behaviour of trace elements from within CCPs used in structural fill layer is an issue that needs to be considered. Testing and environmental risk assessment of the particular site where placement is proposed will determine whether any control measures are required. Leaching of any material generally occurs when that material is subjected to large volumes of water moving through its mass. One of the prime objectives of embankment construction is to minimise seepage and water flow through the fill material. Once CCPs have been placed and compacted, they form a very stable embankment where only very small or no water flow is possible. Thus, a well designed and constructed CCP embankment is likely to have very low negligible trace elements within any leachate that is released.

7. FIELD PERFORMANCE AND APPLICATIONS

One notable project where CCPs have been used in Australia as a structural fill is near Newcastle (NSW) where 170,000 tonne of FBA was used to bridge a well-recognised sensitive wetland location. This project demonstrated a commercial application of CCPs as a structural fill where it continues to provide a sound structural base for the Newcastle Freeway. Figure 2 shows the embankment during its construction. The lightweight and permeable material dramatically reduced the construction period by accelerating the settlement of the foundation sediments and limiting the total settlement.

Fig. 2: F3 Freeway Wetlands Ash Embankment

There have been many applications of CCPs within structural fills on power station sites which continue to work efficiently under high loadings. At Mt Piper power station in New South Wales, an 8 m reinforced earth strap wall was constructed using CCPs as the structural fill material. This was the first structure of this type in Australia to use CCPs ([14]). This structure continues to be used as a ramp support for large bulldozer work at the coal handling plant. Figure 3 shows the ease of compaction as the excavator tracks are supported by the material during placement.

Fig. 3: Spreading and Compaction of Fly Ash - Mt Piper Power Station Reinforced Soil Wall ([9])

Power Producers are in the best position to offer advice and assistance with design and supply of CCPs for construction, as they have in-house knowledge of the properties of their CCPs and it is in their best interests to find suitable applications for these materials to increase the lifespan of their existing ash storages. Detailed information on CCPs and use in structural fills and civil works applications are available in the literature ([15]).

8. CONCLUSIONS

CCPs, either as FA or FBA, can be used either directly as fill materials, or to enhance the mechanical and engineering properties of other fill materials. Importantly, FA not conforming to provisions of AS 3582.1 can be successfully used for these applications. With proper design, selection of suitable materials, placement and compaction, a range of structural fill products and applications can be established.

Engineered fills need predictable performance in order to deliver the requirements of the designer. The consistent and favourable properties of CCPs make them excellent materials for this purpose. The beneficial properties include light weight, ease of compaction and consistent particle size which make for predictable fill performance. Experience in the use of CCPs worldwide has been reported. Limited experience is available for selected applications in Australia, and with further planned R&D work, its use is predicted to increase for both economic and environmental benefit.

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ASH DEVELOPMENT ASSOCIATION OF AUSTRALIA (ADAA)

PO Box 1194 Wollongong NSW 2500 Australia
Telephone: +612 4228 1389 / Fax: +612 4258 0169
Email: adaa@adaa.asn.au / Web: www.adaa.asn.au