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FINAL REPORT

P164 – Task 1: Optimisation of MRTS04 Specification Requirements for Earth Fill Materials

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Summary

Queensland Department of Transport and Main Roads (TMR) earthworks specification, MRTS04 *General Earthworks* (2023) classifies the earth fill materials into 5 classes. This project investigated the requirements and strategies to use non-conforming materials if conforming materials are not available for the road embankment construction. A review of the Australian road and transport agencies' practices indicated that there are no set rules regarding requirements for earth fill materials. However, commonly specified/considered properties are particle size distribution (PSD), California Bearing Ratio (CBR), plasticity index (PI), weighted plasticity index (WPI) and linear shrinkage (LS). The documented requirements for earth fill materials are largely based on the location of the material within the embankment, operating and climatic conditions and performance history of the material. An evaluation of the performance of Class A2 material used in TMR projects where Class A1 material was required indicates that the short-term performance of these materials post-construction appears satisfactory, where vegetation has been established. Since the investigated projects are under construction or newly built, the performance cannot be assessed. The opportunity for desktop modelling was investigated and shows that, currently, there is no software package that considers all variables related to embankment stability in cohesive and non-cohesive materials.

In general, cohesionless materials without cohesive fines, as defined by Class A2 material in the TMR specification for earthworks (MRTS04), have reasonable strength properties but are highly prone to erosion when placed on the outer zones (batters) of embankments. The use of these materials on embankment batters can result in severe erosion caused by rainfall, road surface runoff, and wind.

The potential for erosion due to road surface runoff could be minimised by reducing the pavement and shoulder crossfall to between 1.5% and 2%, as a lower velocity of runoff minimises erosion. Additionally, constructing a kerb close to the crest of the embankment, diverting water through batter chutes, flattening the batter slope to no steeper than 1V:4H, and establishing appropriate vegetation can all be considered to mitigate erosion.

However, no feedback has been obtained from any State Road Transport Authorities in Australia or internationally regarding the effectiveness of these measures. Alternatively, improving these materials by mixing them with other suitable materials can be considered, but this option is generally not preferred by contractors due to its time-consuming and costly nature.

The management of materials for embankment during construction is based on site-specific requirements and the variability of the available materials.

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1. Introduction

1.1 Background

The *General Earthworks* specification (MRTS04-2022) by the Queensland Department of Transport and Main Roads (TMR) outlines six classes of earth fill materials, with Class A1 being the highest quality. Class A1 material is important in embankment construction, either as a homogenous embankment material or for use in the upper and outer zones of zonal embankments.

Recently several construction projects across Queensland have faced challenges where the required quantities of Class A1 material could not be sourced on-site or imported externally. As a result, in some cases, the specification for Class A1 material were either relaxed to allow non-conforming materials or replaced with project-specific material specifications. This situation highlights the need to review TMR's current specification and develop a strategy for using available materials in embankment construction without compromising embankment performance.

This research investigates the suitability of lower quality materials when Class A1 material is not available.

1.2 Scope and Objectives

The aim of the project was to review and suggest the following:

- the suitability of the current Class A1 material specification properties to determine whether minimum design requirements can still be achieved with lower quality materials
- the properties of suitable materials for use in embankment construction (e.g. particle size distribution (PSD), Atterberg limits)
- technical development and stabilisation requirements for different categories or grades of material for stable embankments.

This was achieved through:

- reviewing the practices of other Australian state road and transport agency (SRTAs), including relevant specifications and other technical documents
- assessing evidence of embankment performance from TMR projects where alternative materials have been used for Class A1 applications

1.3 Structure of the Report

The structure and contents of the report are as follows:

- Section 1 provides an overview of the project objectives and scope.
- Section 2 summarises the review of the current practices of Australian SRTAs.
- Section 3 provides details on embankment materials and treatments.
- Section 4 details the outcome of the assessment of embankment performance in Queensland.
- Section 5 summarises the consultation with Australian SRTAs.
- Section 6 outlines the key findings.
- Section 7 summarises the opportunities for TMR.

2. Review of Australian State Road and Transport Agency Practices

2.1 Queensland Department of Transport and Main Roads

The *General Earthworks* specification MRTS04 (TMR 2022) states that the fill materials used in embankments should be either earth fill or rock fill materials sourced from general excavation on-site, borrow areas on or off-site or other stockpiled materials (e.g. quarry materials). Earth fill materials are classified into six classes based on their properties. Table 2.1 summarises the earth fill material properties as defined in MRTS04.

It is important to note that Class A1 includes a minimum PI of 7%, with at least 15% passing the 0.075mm sieve. This is intended to act as a binding agent, helping to bind particles together and provide better resistance to erosion compared to Class A2 materials.

Table 2.1: Earth fill material properties

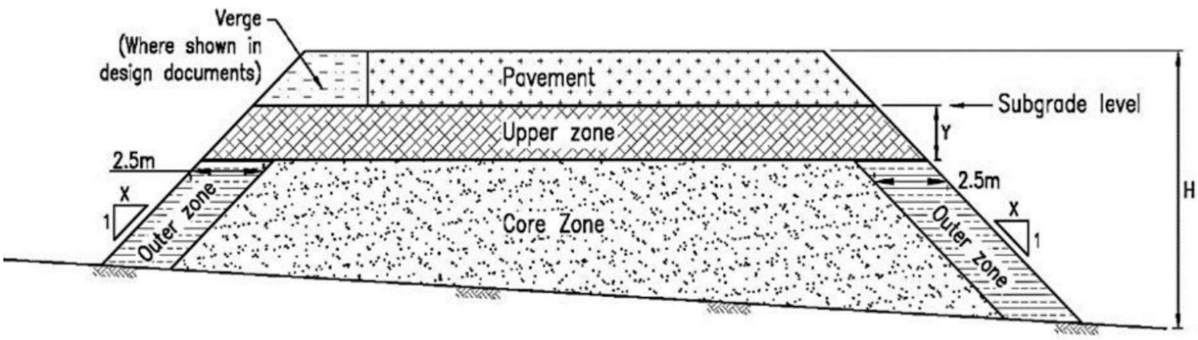
<table>
<tr><th>Earth fill material</th><th>Weighted plasticity index (WPI)</th><th>Plasticity index PI (%)</th><th>Minimum % passing 0.075 mm test sieve</th><th>Coefficient of uniformity</th><th>Emerson class number</th></tr>
<tr><td>Class A1</td><td>< 1,200</td><td>≥ 7</td><td>15</td><td>-</td><td>> 3</td></tr>
<tr><td>Class A2</td><td>< 1,200</td><td rowspan="3">–</td><td rowspan="5">–</td><td>> 5</td><td rowspan="3">Note 1(1)</td></tr>
<tr><td>Class B</td><td>1,200 ≤ WPI < 2,200</td><td>–</td></tr>
<tr><td>Class C</td><td>2,200 ≤ WPI < 3,200</td><td>–</td></tr>
<tr><td>Class D</td><td>3,200 ≤ WPI < 4,200</td><td>< 50(2)</td><td>–</td><td rowspan="2">–</td></tr>
<tr><td>Unsuitable</td><td>WPI ≥ 4,200</td><td>–</td><td>–</td></tr>
</table>

1. Not specified unless required in accordance with MRTS04 Table 14.3.1.
2. Class D material that has PI > 50% (as determined by AS 1289.3.3.1) unsuitable for use as earth fill (refer MRTS04 Clause 9.2d).

Source: TMR (2022).

Figure 2.1 illustrates the embankment zones.

Figure 2.1: Embankment zones as adopted by TMR



Source: TMR (2022).

Table 2.2 summarises the required types of earth fill material for embankment construction.

Table 2.2: Embankment fill properties

<table>
<tr><th rowspan="3">Height (H)</th><th rowspan="3">Batter slope X[1,6]</th><th rowspan="3">Rainfall zone[2]</th><th colspan="4">Zoned cross-section</th><th rowspan="3">Homogeneous cross-section[3,5,7,9]</th></tr>
<tr><th rowspan="2">Upper zone thickness Y (m) [1,4]</th><th colspan="3">Earth fill class[3]</th></tr>
<tr><th>Core[1]</th><th>Upper[1,5]</th><th>Outer[1,5]</th></tr>
<tr><td>≤ 3 m</td><td>≥ 4 m</td><td>Low/Medium</td><td>1.0 m
when Class C in core
and
1.2 m
when Class D in core</td><td rowspan="4">A1, A2, B, C, D</td><td rowspan="4">A1, B</td><td rowspan="2">A1, B, C</td><td rowspan="2">A1, A2, B, C[10]</td></tr>
<tr><td></td><td></td><td>High</td><td>0.8 m
when Class C in core
and
1.0 m
when Class D in core</td></tr>
<tr><td>≤ 10 m</td><td>≥ 2 m</td><td>Low/Medium</td><td>1.2 m
when Class C in core
and
1.5 m
when Class D in core</td><td rowspan="2">A1, B</td><td rowspan="2">A1, B</td></tr>
<tr><td></td><td></td><td>High</td><td>1.0 m
when Class C in core
and
1.2 m
When Class D in core</td></tr>
<tr><td>≤ 10 m</td><td rowspan="2">≥ 1.5 m</td><td rowspan="2">–</td><td rowspan="2">600 mm of Class A1 or Class B[9]</td><td colspan="4">Rock fill, maximum rock size 300 mm</td></tr>
<tr><td>> 10 m[6]</td><td colspan="4">Rock fill, maximum rock size 400 mm</td></tr>
</table>

1. Refer to Figure 2.1 for definitions of X, Y and Core, Upper and Outer Zones.
2. Refer to MRTS04 Table 15.3(c) for rainfall zone definitions.
3. Refer to Table 2.1 for definitions of earth fill classes A1, A2, B, C and D.
4. As the Upper Zone (and Core Zone/Outer Zone) will form part of the pavement subgrade, additional requirements stated in Clause 9.1 of Annexure MRTS04.1 must also be satisfied.
5. Emerson class number > 3 for Outer Zone and Upper Zone materials as well as homogeneous cross-sections.
6. Minimum requirements are given in Figure 2.1 and Table 2.1. Embankments with height (H) > 10 m need to be geotechnically designed (e.g. Outer Zone thickness may need to be increased to satisfy the stability requirements). Material permitted for use shall include Class A1, Class B and Rockfill.
7. For embankments within the Structure Zone of bridge over land, only Class A1 and/or Class B materials shall be used. For embankments within Structure Zone of bridge over water, only Class A1 material shall be used. The maximum particle size shall be 75 mm. Where pre-boring is required for the driving of pre-cast piles through embankment fill, the maximum particle size shall be no greater than 50 mm.
8. For embankments within the Structured Zone of culverts, only Class A1 and/or Class B materials shall be used.
9. A geotextile separator as per MRTS04 Clause 14.3.2 shall be provided.
10. Class C materials shall not be used in the top 300 mm below subgrade level.

Source: TMR (2022).

Where embankments are to be constructed on or against any slopes or batter of existing embankments, steps are to be cut as follows:

- Where the ground surface has a slope steeper than 1V to 8H and shallower than 1V to 4H, a series of horizontal steps not less than 300 mm high should be cut into the ground surface to be covered by the embankment.
- Where the existing slope or batter has a slope steeper than 1V and 4H, a series of horizontal steps not less than 600 mm high should be cut into the ground surface to be covered by the embankment.
- Where the material to be benched is hard rock, as a minimum, a geogrid reinforcement should be placed at least 2 m on either side of this interface or below the subgrade level.

The *Geotechnical Design Standard* manual (TMR 2020) requires that an unreinforced embankment batter slope should not be steeper than 1 (vertical) to 2 (horizontal) for earth fill and 1V to 1.5H for rockfill embankment. Moreover, the vertical height of any single continuous batter should not exceed 10 m. A minimum 4 m wide bench should be provided at the top of any 10 m high single continuous batter.

In addition to the material properties mentioned above, the embankment batter treatment must also comply with Clause 16 of MRTS04 (June 2023).

2.2 Transport for New South Wales

QA Specification R44 (Transport for New South Wales (TfNSW) 2020) specifies the requirements for earthworks materials based on their source (e.g. site won or imported) and location in the embankment (e.g. upper zone of formation, selected material zone). Table 2.3 summarises the TfNSW requirements for earth fill embankment materials.

Table 2.3: Earth fill material requirements

Material type	Location	Property	Criteria
Upper Zone of Formation (UZF) material (other than Selected Material)	Including shallow embankment and Cut/Fill Transition Zone	CBR[1,2]	8 (min)
		PI	25 (max)
Site won Selected Material	Selected Material Zone, upper 150 mm thick layer	CBR[3], characteristic value (Q)	33 (min)
	Selected Material Zone, lower layer	CBR[3], characteristic value (Q)	19 (min)
	For other upper and lower layers	PI	15 (max)
Verge Material	Verge	CBR[3], characteristic value (Q)	19 (min)
		PI	6 (min), 12 (max)
Material in floor of cutting	Floor of cutting	CBR[1]	8 (min)
		PI	25 (max)
Material where depth of excavation is less than specified	Foundation of shallow embankment and Cut/Fill Transition Zone	CBR[1]	8 (min)
		PI	25 (max)

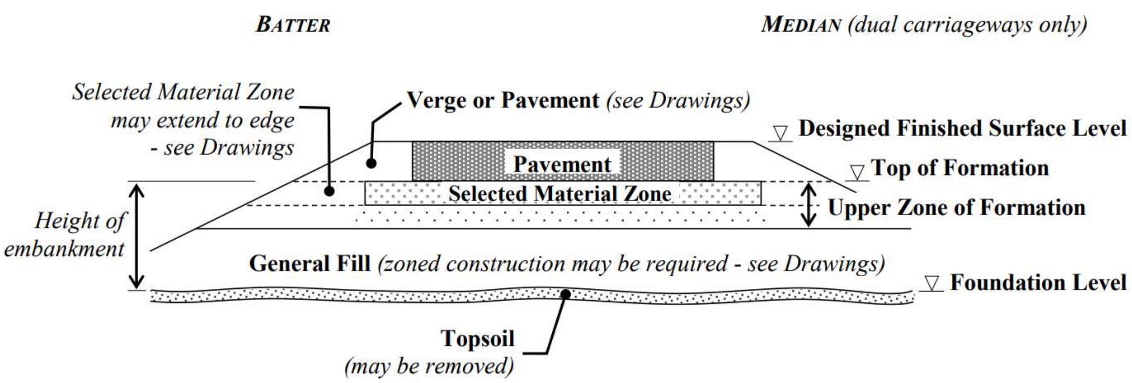
1. 10-day soaked CBR.
2. Compaction for CBR test must be at 100% of maximum dry density (MDD) under standard compaction.
3. 4-day soaked CBR.

Key: CBR: California Bearing Ratio, PI: plasticity index.

Source: TfNSW (2020).

Figure 2.2 illustrates the embankment nomenclature as adopted by TfNSW.

Figure 2.2: Embankment nomenclature as adopted by TfNSW



Source: TfNSW (2020).

Note that any rock material used in earth fill embankment must be broken down to smaller sized particles and evenly distributed throughout the layer to prevent formation of voids in order to produce a dense compact embankment. To meet this requirement, additional fine material needs to be obtained from other places within the site or by changing the method of material processing. Table 2.4 summarises the TfNSW particle size limitations and proportion of rock in earth fill material.

Table 2.4: Maximum layer thickness and proportion of rock in earth fill embankments

Maximum layer thickness (mm)(1)	Maximum quantity of rock (by volume)	Maximum particle dimension (mm)	% passing 37.5 mm AS sieve (by mass)
300	Not specified	200	> 60%
500	25% > 200 mm	300	> 60%

1. Layer thickness (after compaction) should not be less than 100 mm.

Source: TfNSW (2020).

TfNSW (2016) specifies that the general fill should consist of material that can be compacted to not less than 95% maximum dry density (MDD) standard compaction as determined by AS 1289 Tests 5.1.1 and 5.3.1. General fill material should have a minimum PI of 9% and a 10-day soaked CBR of at least 3%.

2.3 Department of Transport and Planning Victoria

Section 204 (VicRoads 2013) specifies the Department of Transport and Planning Victoria (DTP) requirements of embankment materials.

The requirements for Type A material are based on use and location of the material in the embankment. Note that the material classified as silt, either before or after compaction, is not acceptable as Type A material without stabilisation.

Table 2.5 summarises the Type A material requirements.

Table 2.5: Type A material requirements

Location and use of Type A material	CBR(1) % (min)	Swell %	Permeability m/s (max)	Other properties (As assigned)
Capping Layer	As assigned	≤ 1.5	5×10^{-9}	• Limits of grading (% passing by mass) • PI(2) x % passing 0.425 mm post compaction (max) • PI range post compaction
Selected Material	As assigned	≤ 1.5	Not applicable	
Verge Material	As assigned	≤ 1.0	5×10^{-9}	
Structural Material	As assigned	≤ 1.5	Not applicable	
Other Type A Material	As assigned	≤ 1.5	Not applicable	

1. Assigned CBR is to be determined in accordance with VicRoads Code of Practice RC 500.20. Sampling for CBR testing shall be undertaken after field compaction.

Source: VicRoads (2013).

The requirement for Type B material are as follows:

- Material should be totally free of organic content, topsoil, deleterious and/or perishable matter such as bricks, concrete, glass, plastic, timber, steel or steel by-products.
- After compaction, Type B material should have a maximum particle dimension of not more than:
  - 150 mm within 400 mm of the top of Type B material
  - 400 mm at depths greater than 400 mm below the top of Type B material.
- Type B material shall have a minimum assigned CBR (determined in accordance with VicRoads Code of Practice RC 500.20) and assigned per cent swell less than 2.5% (materials that exhibit swell greater than or equal to 2.5 should be classified as expansive). Sampling for CBR testing shall be undertaken after field compaction.
- Material classified as expansive or silt, either before or after compaction, shall not be used as Type B material.

Type C material should be capable of being spread in layers of not more than 500 mm and compacted to achieve a stable condition.

Blends of the crushed recycled materials such as crushed concrete, crushed brick, reclaimed asphalt pavement (RAP), slag and crushed glass may be used as Type A, B and C materials in earthworks applications.

- These blends can only be obtained from a DTP accredited source and manufactured in a controlled manner to ensure the blended product has consistent physical properties.
- Low density foreign materials such as plastic, rubber, plaster, clay lumps and other friable material should not exceed 3% by mass.
- Wood and other vegetable or decomposable matter should be limited to a maximum of 0.5% by mass.
- Crushed glass should be crushed to a cubical shape and be able to pass the 4.75 mm AS sieve.
- Any blend of recycled materials shall be able to be classified as 'clean fill' in accordance with Environment Protection Authority, Victoria guidelines.

Permeable fill material shall be a mixture of hard, durable, clean sand, gravel or crushed aggregate complying with DTP specified requirements.

Note that the topsoil to be placed on formations and disturbed areas should be:

- capable of supporting healthy, full cover of grass growth
- friable, contain organic material
- free from subsoil, tree roots, clay balls, stones, rocks, rubbish, contaminants, weeds, pathogens and toxic levels of any element with a pH in the range of 5 to 8.

2.4 Main Roads Western Australia

Specification 302 (Main Roads Western Australia (Main Roads) 2020) specifies the following requirements for imported material used for embankments, including subgrade.

Table 2.6 summarises the PSD requirements.

Table 2.6: Imported material PSD requirement and other acceptance criteria

Property	Target
PSD requirement(1)	
AS sieve size (mm)	% passing by mass
37.5	80–100
2.36	30–100
0.075	≤ 10
CBR, LS and organic matter requirements	
CBR	12% (min)
CBR swell	1.5% (max)
Linear shrinkage	1% (max)
Glass cullet	20 (max)
Organic matter	1% (max)
Compaction requirements(2)	
Embankment foundation	Perth sands: 90% Other materials: 88%
Embankment construction	Perth sands: 95% Other materials: 90%
Subgrade preparation	Perth sands: 96% Other materials: 92%

1. In addition to meeting above PSD requirement, the imported material should be free from the plant disease Phytophthera Cinnamomi and conforming to the weed and dieback management requirements.
2. Project manager may vary these values as required to suit local conditions and knowledge of existing materials.

Source: Main Roads (2020).

Select fill should be non-cohesive granular material complying with the PSD summarised in Table 2.7.

Table 2.7: Select fill PSD requirement and other acceptance criteria

Property	Target
PSD requirement(1)	
AS sieve size (mm)	% passing by mass
37.5	100
19.0	80–100
9.5	60–100
4.75	45–100
2.36	30–100
1.18	20–100
0.425	5–100
0.150	3–30
0.075	1–10
Other acceptance criteria	
Linear shrinkage(2)	1% (max)
Organic matter	1% (max)

1. The source for the select fill material shall be clean and free from vegetation, contamination and be dieback-free.
2. Linear shrinkage for the portion of the material passing the 0.425 mm sieve.

Source: Main Roads (2020).

Embankment material should be worked in compacted layers not greater than 300 mm or less than 100 mm for cohesive material and not greater than 450 mm and less than 100 mm for sand. Where less than 100 mm is required to be worked, the underlying material should be grader scarified or stabiliser mixed to such a depth that the resulting thickness of the layer to be worked is greater than 100 mm.

2.5 Department for Infrastructure and Transport South Australia

Master specification *Earthworks* (Department of Infrastructure and Transport South Australia (DIT) 2021) specifies the requirements for materials for earthworks in South Australia. Table 2.8 provides details of material classification.

Table 2.8: Earth fill material classification

Classification	A	B	C	General fill	Oversize	D
Material type	Sand-clay, sand, rubble, quarry or pit overburden or by-product	Sand-clay, sand, rubble, quarry or pit overburden or by-product	Sand-clay, sand, clay, rubble, quarry or pit overburden or by-product	Refer to contract documents		
Max. particle size (mm)	75	106	150	150	500	500
PSD (% passing)				Refer to contract documents		
75 mm	100	–	–		–	–
37.5 mm	80–100	80–100	80–100		< 20	–
0.075 mm	0–25	0–35	0–35		–	–
Max. PI (%)	12	15	–		–	–
Max. LS (%)	6	7	–		–	–
Max. WPI	1,000	1,200	1,500		–	–
Shrink swell index Iss (%)	≤ 0.4	≤ 0.7	≤ 1.1		–	–
Emerson class number	–	–	> 2			
Mica, shale and similar laminated materials	Not permitted	Not permitted	Not permitted	Not permitted	Not permitted	Permitted

Source: DIT (2021).

The fill material must be placed and compacted uniformly in layers in accordance with Table 2.9. The contractor may propose layer thicknesses greater than specified. However, the contractor will need to demonstrate through trials that the proposed placement and compaction methodology is able to achieve compaction through the entire layer.

Table 2.9: Fill construction

<table>
<tr><th>Maximum particle size of fill material (mm)</th><th>Layer thickness (mm loose)</th><th colspan="3">Compaction</th><th>Moisture content when compacted</th></tr>
<tr><td>150 or less: Types A, B and C</td><td>150 to 200</td><td colspan="3">In accordance with Clause 14 ‘Verification Requirements and Records’.</td><td>OMC ± 2%</td></tr>
<tr><td>150 or less: General fill</td><td>150 to 200</td><td colspan="3">In accordance with the contract documents.</td><td>In accordance with the contract documents.</td></tr>
<tr><td rowspan="4">> 150</td><td rowspan="4">Minimum layer thickness of 1 and a half times the maximum particle size, or 300 mm, whichever is greater.</td><td>Min. roller classification</td><td>Max. layer thickness</td><td>Min. number of passes</td><td rowspan="4">In accordance with the earthworks management plan.</td></tr>
<tr><td>Class 5</td><td>300</td><td>6</td></tr>
<tr><td>Class 10</td><td>500</td><td>6</td></tr>
<tr><td>Class 12.5</td><td>750</td><td>6</td></tr>
</table>

Source: DIT (2021).

The following actions are to be considered for the stability of the embankment:

- All filling must be supervised by a qualified civil/geotechnical engineer or earthworks site supervisor to address any issues related to fill construction.
- Where new embankment fill is to be placed against an existing surface that is steeper than 3 horizontal to 1 vertical, benching within the existing surface must be carried out to allow placement of fill in layers. The width of benches must be 1 m minimum and must be constructed at 0.5 m vertical intervals to create a stepped surface.
- During construction, the surface grades shall be cut to allow for drainage of surface water to low points where removal of water is possible in a timely manner to prevent softening of subgrade soils or destabilisation of nearby cuttings and retaining structures.
- Any noise mounds must not contain material with a particle size greater than 150 mm and must contain more than 20% finer than 0.075 mm particle size. Fill-in noise mounds may be compacted in layers up to 300 mm loose depth.
- Oversize material (material with a maximum particle size of 150 mm or more) must not be placed within 500 mm of the underside of the pavement and must have the top surface of the material blended with Type A or B material to fill surface voids before the placement of subsequent layers.

2.6 New Zealand Transport Agency

Specification for Earthworks Construction (New Zealand Transport Agency (NZTA) 1997) classifies material to be excavated as Types A, R1, R2, W and U, as defined in Table 2.10.

Table 2.10: Material classification

Material type	Description
Type A	Type A material is all material that does not fall within categories R1, R2, W or U.
Type R1	This is a rock that cannot be productively ripped unless equipment is used that is more powerful than a crawler tractor having net engine power in the range of 100–115 kW and fitted with a twin shanked hydraulic ripper or a 30 tonne hydraulic excavator with a bucket or smaller excavator with a single tyne ripper.
Type R2	This is a rock that cannot be productively ripped unless equipment is used that is more powerful than a crawler tractor having net engine power in the range of 270–310 kW and fitted with a single shanked hydraulic ripper or a 30 tonne hydraulic excavator with a single ripper on the boom.
Ripping trials	Where agreement cannot be reached on classification of Type R1 and R2 materials, productivity trials should be carried out using one of the equipment mentioned above. The engineer will determine the material type from the trial.
Type W	This is material that is too wet for immediate use but is suitable for use in construction fill after drying. This material may be cut to waste if the engineer considers the drying operation to be uneconomic.
Type U	This is material that should not be used in construction fill due to one or more of the following inherent properties making it unsuitable: • grain size • moisture sensitivity • organic content.

Source: NZTA (1997).

The engineer will nominate the material that should not be used in:

- bulk filling (all fill materials placed from the ground surface after clearing and removing topsoil)
- subgrade filling (layer of material in the top 1 m of the construction measured down from the underside of subbase layer).

If cuts do not provide sufficient suitable materials for fills, additional material shall be obtained from nominated borrow areas. Material used in the fill should be spread and compacted in layers of uniform quality and thickness. The thickness of each layer should be limited to ensure that the specified compaction is achieved for the full depth of each layer.

If the material that has already been placed in the fill is considered by the engineer to be too wet, the material should be dried or mixed to be suitable for fill or replaced with suitable material.

The maximum thickness of each layer of fill before compaction should be in accordance with Table 2.11 and Table 2.12.

Table 2.11: Bulk fill

Nominal maximum particle size	Maximum layer thickness
Up to 100 mm	200 mm
100 mm to 200 mm	1.5 times the 85th percentile size
Over 200 mm	Refer contract documents where applicable

Source: NZTA (1997).

Table 2.12: Subgrade fill

Position within subgrade layer	Maximum layer thickness	Maximum particle size (measured on square opening screen)
Lower 600 mm	200 mm	125 mm
Top 400 mm	135 mm	75 mm

Source: NZTA (1997).

2.7 Comparison of Australian Jurisdictions

A review of the Australian SRTAs indicates that there are no set rules regarding the requirements for earth fill materials. Documented requirements for these materials are largely based on the nature of the locally available materials, location of the materials within the embankment, construction experience with those materials, performance history and operating and climatic conditions. Moreover, each jurisdiction has its own requirements. Commonly required properties are PSD, CBR, PI, WPI and LS. Table 2.13 summarises the specification requirements for Australian jurisdictions.

Table 2.13: Summary of specification requirements for Australian jurisdictions

Jurisdiction	Material classification	Nature of requirements	Specification requirements
TMR Queensland	6 Classes of material (A1, A2, B, C, D, unsuitable)	Allowable ranges of WPI and PI	• WPI: < 1,200 to > 4,200 for different classes of materials • PI: ≥ 7% & Emerson class > 3 & min. passing 0.075 mm sieve: (15%) (only for A1 material)
TfNSW	Material type based on location in the embankment	Minimum limits for CBR, CBR characteristic & maximum limit for PI	• UZF[(1)]: CBR 8 min & PI 25 max • Selected material: CBR (Q)[(2)]19 & 33 min & PI (15% max) – based on location in the embankment • Verge material: (CBR (Q[(2)])19 min & PI 6–12% max
DTP Victoria	5 Classes of Type A material based on location, Type B and C materials	Target for swell and permeability	• Capping Layer: Swell ≤ 1.5% & Permeability 5 x 10^{-9} m/s max • Selected material/Structural material/Other Type A material: Swell ≤ 1.5% • Verge material: Swell ≤ 1.0% • Type B material: Swell < 2.5%

Jurisdiction	Material classification	Nature of requirements	Specification requirements
Main Roads, WA	Imported material, Select fill	Target for PSD, CBR, LS, glass cullet, organic matter	• Imported material: – % Passing by mass 37.5 mm (80–100), 2.36 mm (30–100), 0.075 mm (≤ 10) – CBR (12% min) – CBR swell (1.5% max) – LS (1% max) – Glass cullet (20 max) – Organic matter (1% max) • Select fill: – % Passing by mass 37.5 mm (100), 19.0 mm (80–100), 9.5 mm (60–100), 4.75 mm (45–100), 2.36 mm (30–100), 1.18 mm (20–100), 0.425 mm (5–100), 0.150 mm (3–30), 0.075 mm (1–10) – LS (1% max) – Organic matter (1% max)
DIT SA	Classification based on material type i.e. A, B, C, General fill, oversize, D	Maximum particle size, PSD, PI, LS, WPI, Iss(3), Emerson class, deleterious laminated materials	• PSD % Passing 75 mm A (100), 37.5 mm A,B,C (80–100) • PI A (12 max), B (15 max) • LS A (6 max), B (7 max) • WPI A (1,000 max), B (1,200 max), C (1,500 max) • Iss(3) A (≤ 0.4 max), B (≤ 0.7 max), C (≤ 1.1 max) • Emerson class C (> 2) • Mica, shale and similar minerals – not permitted.
WALGA(4)	General fill, Select fill	PSD, LS, organic matter, foreign materials	• General fill: – PSD % Passing 37.5 mm (80–100), 2.36 mm (30–100), 0.075 mm (0–10) – LS ≤ 3 – Organic matter = ≤ 1% – Brick/tile, plastic/plaster, wood/plants < 5%, < 2% & < 1% respectively • Select fill (same as Main Roads' requirements)

1. Upper Zone of Formation.
2. CBR characteristic value.
3. Shrink Swell Index.
4. Western Australian Local Government Association.

Source: Technical documents of Australian jurisdictions referenced wherever applicable.

The properties such as PSD and Atterberg limits decide how material should be handled and placed in the embankment e.g. compaction level and testing method and procedure. There are no nationwide acceptable material properties requirements.

3. Embankment Materials and Treatments

3.1 Embankment Materials

The most suitable materials for road embankment construction should provide stability, durability, and resistance to various environmental conditions. Well-graded granular materials, such as gravelly sandy soils with some clay content, are often preferred for their compaction potential, leading to robust embankment fills. Silt-based materials are generally avoided due to their low strength, tendency to retain water, and susceptibility to erosion. Materials with high expansion properties are also unsuitable for embankments. Additionally, highly erodible or dispersive materials are not suitable, particularly on the embankment batter. Adequate compaction of earth fill materials is typically controlled through field density measurements.

Woods (1939) provides the density soil classification based on maximum laboratory dry density and minimum field compaction requirements. Table 3.1 summarises the field compaction requirements for different fill heights.

Table 3.1: Density soil classification

Condition 1 Fills 3 m or less in height and not subject to extensive floods		Condition 2 Fills exceeding 3 m in height or subject to long periods of flooding	
MDD (t/m^3)(1)	Minimum field compaction requirements (Percentage of MDD)	MDD (t/m3)(1)	Minimum field compaction requirements (Percentage of MDD)
< 1.440	(2)	< 1.520	(3)
1.441–1.600	95	1.521–1.60	100
1.601–1.761	95	1.61–1.761	100
1.762–1.921	90	1.762–1.921	95
1.922–2.081	90	1.922–2.081	90
2.082 and more	90	2.082 and more	90

1. MDD is obtained as described in Bulletin No. 99, Ohio State University Engineering Experiment Station.
2. Soils that have MDD of less than 1.440 t/m^3 shall be considered unsatisfactory and shall not be used in embankment.
3. Soils that have MDD of less than 1.520 t/m^3 shall be considered unsatisfactory and shall not be used in embankment under condition 2 requirements.

Source: Adapted from Woods (1939).

3.2 Managing Embankment Batter Erosion

Hard surface treatments, such as shotcrete, can be considered for batter protection. However, due to high costs and aesthetic concerns, hard surface treatment is generally not preferred as a suitable batter treatment. A popular technique to stabilise road embankment batters and prevent soil erosion is planting vegetation on the batters. However, the use and installation of the vegetation primarily depend on the soil type and slope attributes, such as steepness. The *Guideline for Batter Surface Stabilisation Using Vegetation* (Roads and Maritime (RMS) 2015) provides guidance on achieving batter stability primarily through vegetation.

A key consideration is that the batter slope gradient should be appropriate for the geotechnical and erosion characteristics of the soil. In general, topsoil should not be placed on slopes steeper than 2H:1V without any additional stabilisation measures, as there is a high risk of the topsoil slipping off the slope. Upstream surface flows should be diverted away from the batter to prevent erosion. The erosion potential varies: raindrop splash has minimal erosion potential, sheet flow has moderate erosion potential, and concentrated flow has high erosion potential. Erosion from long slope could be minimised by breaking up the slope length with benches or terraces, which help capture surface runoff and direct it to a stable outlet, minimising erosion and preventing ponding.

Batter surface stabilisation can be achieved through various methods:

- Directly spraying bitumen emulsion: This method uses bitumen emulsion as a soil binder to glue the soil particles together, forming an erosion resistant crust. An anionic slow-setting emulsion is suitable for this purpose. Cationic bitumen emulsion, which is typically used for road sealing, is not suitable for vegetation areas. The typically recommended application rate is 1 L of undiluted residual bitumen emulsion per square metre. It can be diluted up to 50/50 with water and the diluted emulsion should be sprayed to achieve the application rate (1 L/m^2).
- Spraying tackifiers (polymer cementitious or organic ingredients): These are mixed with water and applied to batters hydraulically. Commonly used products include guar gum, starch based and engineered polymer based tackifiers. The effectiveness of tackifiers can be significantly affected by soil type. Heavy and well-compacted soils may limit the tackifiers' ability to penetrate the soil and form a sufficiently thick surface crust. Some tackifiers are biodegradable, while others are photo/chemical degradable; thus, their impact on the downstream environment should be considered.
- Applying mulches: A blanket of mulch can be laid directly over the batter surface to be vegetated, using hydraulic, air blown, mechanical or manual spray methods. Mulches include straw, shredded vegetation, woodchip and blended mulches.
- Using straw mulching: Cereal or cane toppings can be applied to the soil to provide erosion protection. This method can be combined with bitumen emulsion or tackifiers. Hydromulching involves spraying organic fibre materials mixed with water onto the surface in slurry form, creating a temporary protective layer against wind and water erosion. Hydromulching includes standard mulching, bonded fibre matrix, and hydrocompost.
- Rolling erosion control blankets: These blankets are composed of organic fibres and synthetic materials and are laid onto the soil surface.
- Installing cellular confinement systems: permanent or biodegradable systems uniformly contain soil and other material over an area, providing geotechnical strength. A compost blanket consists of high-quality compost, organic tackifiers, biological stimulants, wetting agents, soil ameliorants and seed mix. These systems can also be applied on steep slopes where topsoil application is not feasible.
- Applying turf reinforcement mats: These mats are composed of 2 or 3-dimensional rolled mats made from a dense mesh of synthetic polymers.

Table 3.2 summarises the details of slope dimensions, level of erosion protection and effectiveness for the above-mentioned techniques.

Table 3.2: Summary of embankment erosion protection techniques

Technique	Slope	Level of protection	Effectiveness duration	Cost (as per 2015 estimate)
Bitumen emulsion	≤ 3h:1v	Withstand raindrop splash and low velocity sheet flow	3 to 12 months (can be enhanced if combined with straw mulch or organic fibre erosion control blankets)	Moderate $1 to $5/$m^2$ (depending on location) Additional $3 to $5/$m^2$ to strip and respread topsoil if required
Tackifiers	≤ 3h:1v	Withstand raindrop splash erosion and sheet flow	Short term Varies dramatically from one month to more than a year based on product used, application rate and type of activity on the batter	Low $0.15 to $0.50/$m^2$ Additional $3 to $5/$m^2$ to strip and respread topsoil if required
Mulch	≤ 4h:1v 1.5H:1V (may be)	Excellent for most erosion types except concentrated flow. Mineral mulches (including rock mattresses) should be used on non-dispersive soils	Extremely variable 2 to 12 months depending on the type of mulch used.	Low (Contact suppliers) Additional $3 to $5/$m^2$ should be allowed to strip topsoil (if required) then mix with mulch and respread.

Technique	Slope	Level of protection	Effectiveness duration	Cost (as per 2015 estimate)
		in locations of concentrated flows		
Straw mulching	≤ 2h:1v	Raindrop splash erosion only	2 to 6 months	Moderate $0.60 to $5/m² Additional $3 to $5/m² to strip and respread topsoil if required.
Hydromulching – standard	≤ 3h:1v	Raindrop splash erosion and low volume sheet flow	2 to 6 months	Low $0.70 to $2.50/m² Additional $3 to $5/m² to strip and respread topsoil if required.
Hydromulching – bonded fibre matrix	≤ 1h:1v	Raindrop splash erosion and sheet flow (may withstand sheet flow if combined with other techniques)	6 to 12 months	Moderate $2.50 to $4.50/m² Additional $3 to $5/m² to strip and respread topsoil if required.
Hydromulching – hydrocompost	No limits	Raindrop splash erosion or sheet flow (may withstand sheet flow if combined with other techniques)	6 to 12 months	Moderate $3.50 to $6.50/m² Additional $3 to $5/m² to strip and respread topsoil if required.
Erosion control blanket – organic fibre	No limit	Raindrop splash impact and sheet flow	Up to 12 months	High $5 to $10/m² Additional $3 to $5/m² to strip and respread topsoil if required.
Erosion control blanket – synthetic	No limit	Withstand sheet flow up to ~ 1.5 m/s	Up to 2 years	Very high $5 to $10/m² Additional $3 to $5/m² to strip and respread topsoil if required.
Cellular confinement systems	≤ 1h:1v	Raindrop splash erosion, sheet flow and low velocity concentrated flow	Up to 4 years	Very high $20 to $30/m² Additional $3 to $5/m² to strip and respread topsoil if required. Additional cost for soil anchors.
Compost blanket	≤ 2h:1v	Raindrop splash erosion and sheet flow. May withstand low velocity concentrated flow if combined with other techniques	6 to 12 months	High upfront cost $3.50 to $12/m² Topsoil is not required. Maintenance costs are often minimal.
Turf reinforcement mats	≤ 3h:1v	Raindrop splash erosion, sheet flow and concentrated flow	Designed as permanent stabilisation technique (product will eventually break down).	Very high $12 to $35/m² To supply and install.

Source: RMS (2015).

The Western Queensland Technical Note (Carbery et al. 2005) provides guidance on managing roadside erosion. It recommends that batter slopes be between1V:4H and 1V:6H and be designed to be traversable for maintenance purpose. These slopes are generally flattened to control water velocities. Additionally, the batter slopes should be concave at the toe to counteract the tendency for water velocities to increase further down the slope.

4. Assessment of Embankment Performance in Queensland

4.1 Project and Material Details

In 2023, TMR provided information related to projects where alternative materials (i.e. minus 75 and minus 200 material, which belong to Class A2 materials) have been used for homogeneous and outer zones of zonal embankments. The information provided is based on observations of the performance of these materials. Table 4.1 summarises the embankment construction and performance details as reported in 2022.

Table 4.1: Summary of embankment construction and performance

Site/Project	Project Status	Embankment construction type	Height (m)	Batter geometry	Materials used	Observations
Townsville Ring Road Stage 5 (TRR5) – Beck Drive Overpass Southern Approach	Under construction	Zoned	8–10	1V:2H	Core – sodic soil Outer 2.5 m – 75 minus (Class A2) Upper 1–1.5 m – 75 minus (Class A2)	• Scouring on RHS batter • Depth of scouring approximately 200–300 mm. • Segregation of coarse and fine materials • Subgrade or surface of upper zone is well compacted and sealed.
Townsville Ring Road Stage 5 (TRR5) – Beck Drive Southbound Off-Ramp over Kern Drain Culverts	Under construction	Zoned	5	1V:2H	Core – sodic soil Outer 2.5 m – 75 minus (Class A2) Upper 1–1.5 m – 75 minus (Class A2)	• Appropriate fine content with some plasticity • There is no evidence of scour or erosion. However, it is too early to comment on the performance, as the reference document is based on observations made during the construction phase. .
Townsville Ring Road Stage 5 (TRR5) – Little Bohle River Southern Approach	Under construction	Homogeneous	3–4	1V:2H	75 minus (Class A2)	• There is no evidence of scour or erosion. However, it is too early to comment on the performance, as the reference document is based on observations made during the construction phase.
Townsville Ring Road Stage 5 (TRR5) – Herveys Range Road Overpass (Abutment A)	Under construction	Zoned	8	1V:2H	Core – sodic soil Outer 2.5 m – 75 minus (Class A2) Upper 1-1.5 m – 75 minus (Class A2)	• No major evidence of scour or erosion. However, it is too early to comment on the performance, as the reference document is based on observations made during the construction phase. • Minor loss of fines • Minor segregation of fine and coarse material • Batter has been treated with polymer erosion control/soil binder product (green glue).
Townsville Ring Road Section 4 (TRR4) – Shaws Road Bridge Approach	Existing (Construction was completed in 2016)	Homogeneous	8–10	1V:2H	Minus 200 (Class A2)	• Well established vegetation cover (grass) • Concrete batter chutes and channelling have been

Site/Project	Project Status	Embankment construction type	Height (m)	Batter geometry	Materials used	Observations
						installed as part of drainage design.
Bruce Highway (Cluden to Vantassel) – Abbot Street Overpass, Southern Approach	Existing (Construction was completed in 2014)	Homogeneous	5	1V:2H	Minus 75 (Class A2) Requirements: General fill: CBR 3 min.	• No evidence of scour or erosion in 2022 • Well-vegetated batter with small trees, shrubs and grass cover near abutments • Grass covering landscaping treatment • Concrete batter chutes and channelling have been installed as part of drainage design.

Source: TMR Internal Report dated April 2022 (shared by TMR).

4.2 Embankment Performance

Based on the observations and basic data provided by TMR, the following comments can be made related to the material performance:

- Four sites (Townsville Ring Road (TRR5) – Beck Drive Overpass Southern Approach, TRR5 – Beck Drive Southbound Off-Ramp over Kern Drain Culverts, TRR5 – Little Bohle River Southern Approach and TRR5 – Herveys Range Road Overpass (Abutment A)) were under-construction at the time of inspection in 2023.
- Two sites (Townsville Ring Road (TRR4) – Shaws Road and Bruce Highway) are operational.
- All the operational sites are homogeneous construction, whereas all the under-construction sites are zoned except Townsville Ring Road TRR5 – Little Bohle River Southern Approach.
- All sites were constructed with Class A2 material with maximum 10 m height and 1v:2h batter slope.

The observations as reported by TMR indicate that there is limited or no evidence of scouring or erosion except at Townsville Ring Road (TRR5) – Beck Drive Overpass Southern Approach where scouring with 200–300 mm depth was observed. Apparently, appropriate drainage has been provided.

It is too early to comment on the performance of these materials during construction, as more time is needed to observe their response to operational conditions. Additionally, while the short-term post-construction performance at the Townsville Ring Road Shaws Road and Cluden to Vantassel Road sites appears satisfactory, this does not provide conclusive evidence that long-term performance risks have been addressed by using these materials.

4.3 Opportunity for Erosion Modelling

Although erosion modelling was not a part of the original project scope, TMR intended to explore the opportunity for erosion modelling to theoretically validate whether the nominated minimum PI of 7% and required fines of 15% for Class A1 material are appropriate. Therefore, this was investigated, and researchers from Griffith University were contacted to discuss:

- any relevant published literature, studies or software
- methods for desktop modelling of soil PSD and plasticity
- small scale mobile fume modelling
- estimated consulting costs.

Based on discussion with the researchers, the currently available software packages do not fully consider all the variables, such as PSD, moisture, Atterberg limits, density and batter slope. Therefore, a suitable software package for modelling embankment erosion was not identified.

5. Consultation with Australian STRAs

The relevant staff in other Australian STRAs were contacted for the consultation and the discussion has been summarised below.

5.1 Transport for NSW

Discussion with TfNSW staff focused primarily on embankments, with an emphasis on general fill materials containing little or no cohesive fines. TfNSW has not reported any issues with these materials. In most cases, general fill materials contain clays and fines, and there are no specific material quality requirements.

Embankment construction focuses on testing material properties (Table 2.3) as well as density, moisture, Benkelman beam deflection testing and proof rolling. As described in Section 2.2, there is a greater focus on material properties for the upper layers. Where earth fill materials have been used, the contractor is required to achieve the specified compaction by adding sufficient water and achieving improved compaction with a static roller. The material issues associated with pavement layers are managed by appropriate stabilisation of the selected material zone (Figure 2.2).

In terms of materials specification requirements, TfNSW can accept lesser quality materials in terms of CBR and PI. If this happens, the pavement design is modified to accommodate this change. TfNSW does have a specification for rock fill that specifies a grading requirement as there is a requirement for particle contact. For general fill material, it is required that the material is free of organics with no other exclusions. For embankment stability, changes may be required to batter slopes when alternative materials are used. Such changes typically occur on the project level to address project-specific requirements. Generally, vegetation is used for batter stabilisation. There was a failure in Western Sydney due to heavy rain and unestablished vegetation at a slope of 2H:1V.

A summary of the discussion with TfNSW staff is as follows:

- There is no specific requirement for general fill. For quality assurance, achieving a specified density, moisture, passing proof roll and Benkelman beam test are required.
- The material to be used is generally required to have sufficient fine content.
- Erosion potential is managed through proper vegetation.

5.2 Department of Transport and Planning Victoria

Based on discussion with DTP staff, there is no practice for using non-conforming or lesser quality materials in road embankment construction in Victoria. Materials used in embankment construction are required to meet relevant specifications to ensure stability, settlement and water infiltration requirements. General fill material is only permitted on the slopes. For the core section of the embankment, Type C material is not permitted, and only Type B or Type A material with assigned properties is used.

5.3 Main Roads Western Australia

Main Roads specifies the PSD requirements for imported materials and selected fill with compaction requirement of 90% and 95% relative compaction, respectively. The compacted layers of sand should be 100 mm to 450 mm thick. Sand and sandy materials are commonly used materials in Western Australia. There is no practice for using non-conforming and lesser quality materials.

6. Key Findings

Four key elements are vital for the long-term performance of road embankments: proper selection of materials, adequate moisture control, uniform compaction and appropriate erosion control as required.

Materials for road embankments are generally identified based on their PSD, Atterberg limits, plasticity, in situ moisture and density. It is challenging to assign engineering properties to the materials during investigation due to variability between different sampling locations. Therefore, proper adjustments need to be made in the field when these changes occur. Sometimes, undesired materials (having high shrink/swell properties) are required to be used in embankment construction due to availability and economic constraints. These marginal materials demand proper control on moisture and compaction for their placement in the embankment.

The compaction equipment configuration can under- or over-compact the materials based on soil type, moisture content and layer thickness.

The requirements for the embankment batter protection may vary from project to project based on the local conditions such as availability of the materials, height and gradient of the batter slope and climate. The selection of the stabilisation technique based on risk assessment is key to maintaining the road embankment at a reasonable cost.

TMR specifies Class A1 material is required for the upper and outer zones of embankment. Australian SRTAs specify PI, PSD, CBR and swell requirements in their relevant specifications. TMR specifies PI and per cent passing 0.075 mm test sieve, TfNSW specifies CBR and PI requirements, DTP Victoria mainly specify swell requirements, Main Roads specifies PSD requirements and DIT specifies PSD and PI requirements. It should be noted that there is no uniformity in terms of materials' properties requirements. Moreover, the requirements are not specific to different categories of materials.

Based on review of the practices and consultation with Australian SRTAs, use of cohesionless material for embankment is generally not a problem.

7. Opportunity

In summary, the management of materials for embankment is based on site-specific requirements and variability of the available materials. Australian SRTAs contacted as a part of this project did not report any significant performance related issues in embankments. Coarser materials with low cohesive fines have successfully been used in road embankment construction with appropriate compaction methods. Based on the project findings, it is not recommended to relax the MRST04 specification to use Class A2 material to replace Class A1 material. However, based on project-specific requirements, Class A2 material could be trialled with appropriate design and construction practices and performance monitored to improve the practice of using Class A2 material to replace A1 material where required.

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