ATC Williams

REPORT

MANDALAY RESOURCES

Costerfield Mine – Brunswick TSF

Probabilistic Seismic Hazard Analysis Report

December 2020

109014.08 R01

ADVERTISED PLAN

Document History and Status

Title: Probabilistic Seismic Hazard Analysis Report

Job Number/Extension: 109014.08

Document Number: 109014.08 R01

Project Office: Melbourne

File Path: K:\Projects\109\109014 Costerfield Mine, Costerfield\08 PSHA Study\Documents\R01\Text\Final Report SM\109014.08 R01.docx

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Rev.	Status	Issued to	Issue Date	Signatures	
				Author	Reviewer
0	Final	Client	10/12/2020	SM	GG/TN

This revision distributed to:	Hard Copy	Electronic Copy
Mandalay Resources		☑
ATCW Melbourne Office		On network

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1 INTRODUCTION

1.1 Overview

Costerfield Mine is an underground mining operation, owned by Mandalay Resources, located in the central Victorian Goldfields region. The Brunswick Tailings Storage Facility (Brunswick TSF) is one of 2 active TSFs at the Costerfield Mine, the other being the Bombay TSF. ATC Williams Pty Ltd (ATCW) has been requested to undertake a site specific Probabilistic Seismic Hazard Assessment (PSHA) for the Costerfield site. This assessment was requested as part of the work to facilitate the raise of the Brunsiwck TSF. It is considered suitable to also use for any design work associated with the Bombay TSF.

This report details the aims of the PSHA, the methodology employed, the data interpretation and interpolation undertaken, the associated calculations, and the results of the study. The report serves to provide a greater understanding of the seismic history and future potential seismicity surrounding the Costerfield site.

The work was carried out in accordance with ATCW's proposal (ref: 109014.07-P01) dated 16 September 2019 and Mandalay Resources Purchase Order No. 0748657.

1.2 Aims of PSHA

ATCW was engaged by Mandalay Resources to undertake a site specific PSHA for the mine as part of the design for the raise of the Brunswick TSF.

The aims of the PSHA are to:

1. Develop a Uniform Hazard Spectrum (UHS) for the site at the bedrock level, in accordance with current best practice (ANCOLD, 2019)**[1]**, with annual exceedance probabilities (AEPs) of earthquakes corresponding to the following return periods:

- 475 years;
- 1000 years;
- 2000 years;
- 5000 years, and
- 10,000 years.

2. Obtain a set of five time histories of earthquake accelerations at bedrock for a return period of 5,000 years. These time histories could also be used for further site seismic response or deformation analyses, if required.

The technical outputs of the PSHA are summarised as follows:

- Hazard curves 5% damped: This is the relationship between ground motion level and annual frequency of exceedance;
- UHS which indicates the frequency dependent spectral acceleration response resulting from all earthquakes expected for a given return period, above the minimum considered magnitude;
- Deaggregation of a plot indicating the contributions to the total hazard from each magnitude and distance combination. The plot is determined for a specified ground motion frequency and return period (a return period of 2,000, 5,000 and 10,000 years). This also enables appropriate earthquakes to be chosen for time history calculations; and

- Time history of accelerations which have been spectrally matched to the UHS for the 5000-year return period.

1.3 Background

Costerfield, which is located approximately 50 km southeast of Bendigo, Victoria, (as shown in **MAP 1**), comprises two areas that have been used for tailings storage to date, Brunswick TSF and Bombay TSF. The co-ordinates of the Brunswick TSF are taken as 36.887 ^{o}S latitude and 144.764 ^{o}E longitude for the purposes of the calculations presented in this report.

MAP 1 - COSTERFIELD SITE LOCALITY (SOURCE: GOOGLE EARTH 2020)

Historically, the Brunswick TSF has been raised using a downstream methodology. Mandalay Resources' preference is to utilise upstream raise methodologies for future embankment raises. It is understood that future raises may increase the height of the TSF by up to 9 m. This work would be undertaken in three stages to provide afinal embankment elevation of RL 1202 m (mine datum).

2 METHODOLOGY

Seismogram recordings are used to determine information about the earthquake source (magnitude, focal mechanism) and travel path (distance, attenuation), and then the inverse of these are used to estimate the ground motion at the site. The earthquake history of the area can be used to estimate the earthquake recurrence rate as a function of magnitude. Combining the recurrence rate and the ground motion model enables the estimation of ground motion recurrence, the most commonly used measure of earthquake hazard.

The methodology for development of the PSHA is summarised under the following sub-headings:

- **Desktop Seismic Source Assessment**

  Review and analyse available literature on the regional tectonics, geology, and seismicity.

- **Historical Seismicity Compilation**

  Obtain regional seismicity data from all available sources and prepare a historical seismicity magnitude that contains the following information for each earthquake event: date & time, epicentral location, focal depth, and magnitude (or intensity if magnitude is unknown).

- **Characterize Regional and Local Seismic Sources**

  Review the literature compiled during desktop seismic source assessment and the seismicity data compilation and incorporate three existing seismic source models (AUS6, DIM-AUS and NSHM 13 (NSHM13 BG)) together with active faults in each of the areas considered (sourced from National Seismic Hazard Assessment 2018 Project, NSHA-18). The maximum distance to be considered in this analysis is 400 km from the TSF. It should be noted that earthquakes with an epicentre located greater than 400 km from the site would have a negligible effect on the seismic hazard **[2]**.

- **Estimate Earthquake Recurrence Rates**

  Determine earthquake recurrence equations for each seismic source delineated during Characterize Regional and Local Seismic Sources. Where available and applicable, geological slip rates and GPS rates will be considered in developing the recurrence rates. The recurrence equations will be truncated at maximum magnitudes, which will be determined from the seismicity and tectonics. Multiple magnitudes and associated weights will be assigned for each significant seismic source to account for the uncertainty in this parameter.

- **Ground Motion Models (GMM)**

  Review appropriate Ground Motion Models (GMM) that are compatible with the tectonic earthquake categories and site conditions and select several GMMs considered to be most applicable to the site. The average shear wave velocity in the upper 30 m (Vs_{30}) of 760 m/s will be used to represent the bedrock at the site.

- **Probabilistic Seismic Hazard and Deaggregation Analyses**

  Undertake a PSHA for the Costerfield using EZ-FRISK™ software which uses logic trees to take account of uncertainties in the earthquake source and Ground Motion Models. The hazard calculations use a lower bound magnitude of Mw 5.0. Probabilistic ground motion response spectra are developed for return periods of interest at the bedrock **[4]**.

  Based on the results of the seismic hazard analysis, the hazard is then deaggregated to identify the magnitude and distance combinations of the earthquakes that control the seismic hazard for return periods of interest.

- **Ground Motion Time Histories and Spectral Matching**

  A suite of five ground motion time histories have been selected from recorded earthquakes to represent the controlling earthquake for a 5000-year return period using the results of deaggregation analyses in in Probabilistic Seismic Hazard and Deaggregation Analyses. The selected time histories have been spectrally matched to the relevant UHS.

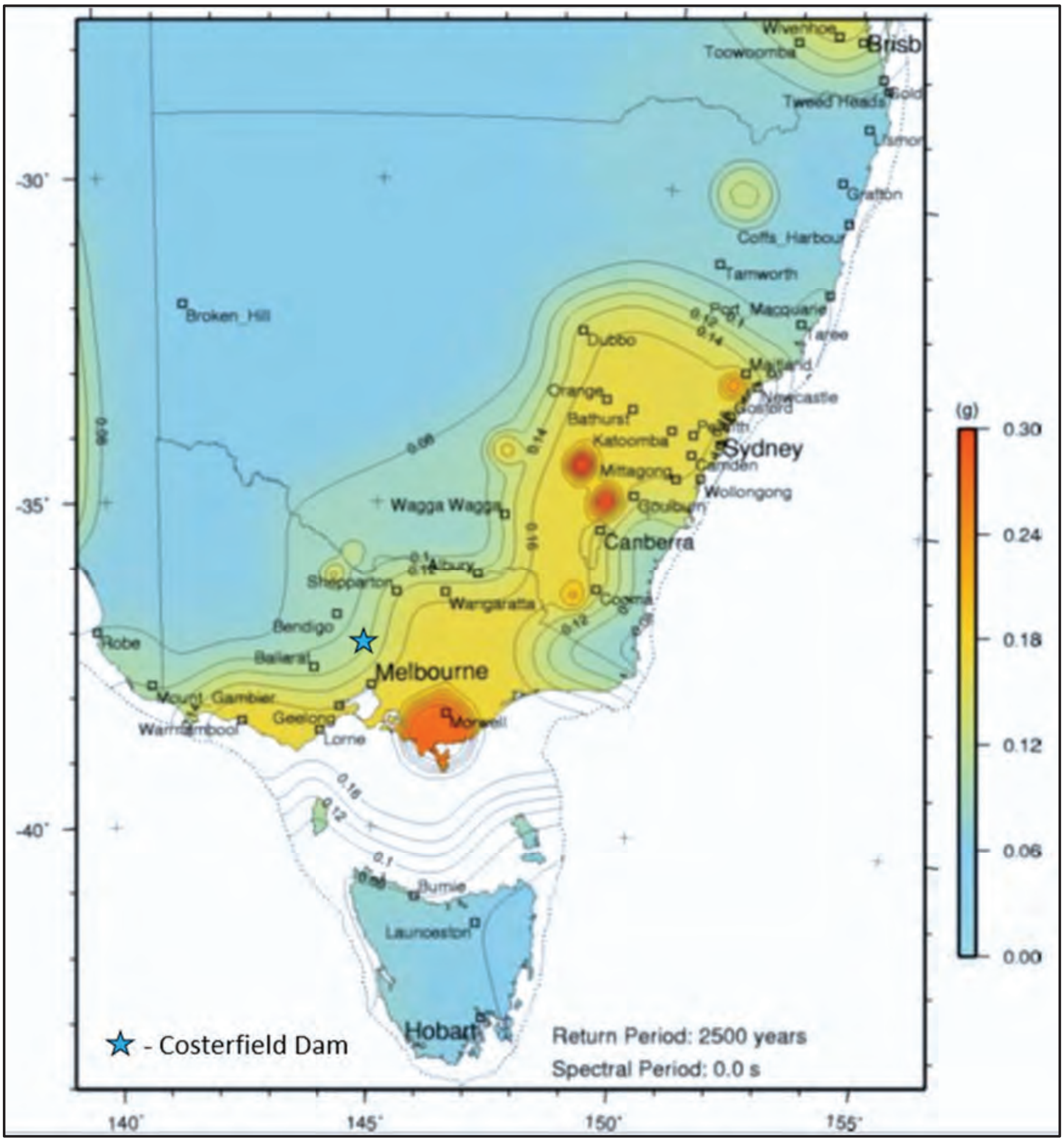
- **Reporting**

  A report is prepared incorporating all aspects of the analysis.

3 PAST SEISMIC HAZARD STUDIES

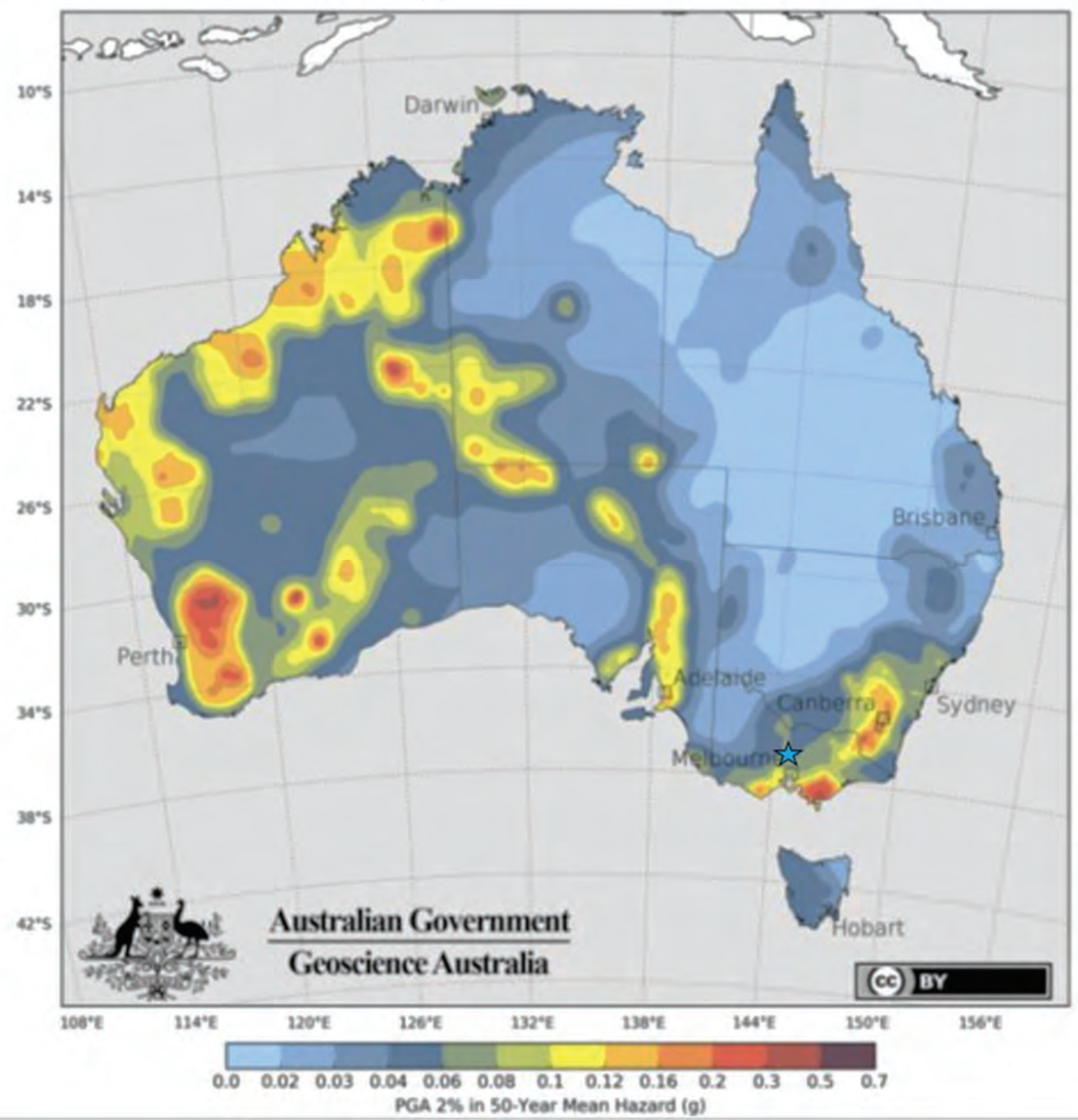
Illustrated in **MAP 2** is the approximate site location (denoted by the blue star) on the 2012 Australian Earthquake Hazard Map **[4]**. Based on this map, the Peak Ground Acceleration (PGA) for return period of 2500 years at the site is between 0.1 and 0.12g for Costerfield Gold Mine.

MAP 2 -2012 NSHA EARTHQUAKE ZONATION MAP FOR NEW SOUTH WALES, VICTORIA AND TASMANIA PGA (PEAK GROUND ACCELERATION) AT 2500 YEAR RETURN PERIOD [4].



In 2018, Geoscience Australia (GA) published a new set of earthquake hazard maps for consideration in the next revision of the earthquake loading code AS1170.4 (2007)**[5]**. According to the new earthquake hazard map, the Costerfield site has a PGA between 0.08 and 0.1g for 2475 return period as shown in **MAP 3** (approximate location shown by blue star). This is significant reduction in the seismic hazard at this site for this return period.

MAP 3 - NSHA18 HAZARD MAP INDICATING THE MEAN PGA FOR 2% PROBABILITY OF EXCEEDANCE IN 50-YEARS (2475 YEAR RETURN PERIOD) ON AS1170.4 SITE CLASS B_e (EQUIVALENT TO Vs_{30} = 1000 m/s)[3].



The key reasons for this decrease in seismic hazard factors from the 2012 to 2018 seismic hazard map are:

- A correction in the rates of moderate-to-large earthquakes ($M_W \geq 4.0$); due to correction of pre-1990 local magnitude ML estimates and the conversion of M_L to moment magnitude MW (as MW is considered to be a more stable scale for larger magnitude events). The occurrence rates of moderate-to-large earthquakes in the preferred NSHA18 earthquake catalogue have roughly halved relative to the original catalogue magnitudes as the result of these corrections;

- An increase in Gutenberg and Richter (1944) b-values, particularly in eastern Australia, as a result of the ML to MW conversions. This has the result of effectively decreasing the rates of rare large earthquakes relative to moderate-magnitude earthquakes; and
- The use of modern ground-motion models (GMM) that do not rely on the PGV to PGA conversions. The recent GMM also predict faster attenuation of PGA with distance, and thus lower ground-motion hazard.

Allen et al (2018)**[3]** also added that whilst the seismic hazard for 1/500 exceedance probability is generally much lower than that in the AS1170.4–2007, the probability factor (kp) generally shows a faster increase with decreasing probabilities relative to the kp factors in the new Standard. The probability factor in AS1170.4 compared to the increase in the probabilistic hazard at an response spectral acceleration (RSA) period of 0.0s (PGA) in the new map. In all case the probabilistic hazard increases faster (has a higher Kp value) in the new assessment than the kp factors in AS1170.4 would indicate. Probability factor is also generally higher for the lower hazard areas (e.g. Brisbane and Hobart) than for the areas with a higher 500year PGA hazard like Adelaide or Sydney **[7]**. The national average of kp at the 1/2500 exceedance probability is 3.15 as compared to 1.8 in the AS1170.4–2007. This means that the differences between the NSHA18 and the current hazard design factors in the AS1170.4 are less pronounced at lower exceedance probabilities.

Despite its availability, the new NSHA18 national earthquake hazard map does not provide hazard values for lower exceedance probability down to 0.0001 (equal to 1:10,000 years return period), which is often required by major infrastructures like tailings dams. Also, this map is not intended to replace the site-specific seismic hazard studies for tailings dam structures because the NSHA18 is a national-scale product and applicable for general civil infrastructures **[2]**.

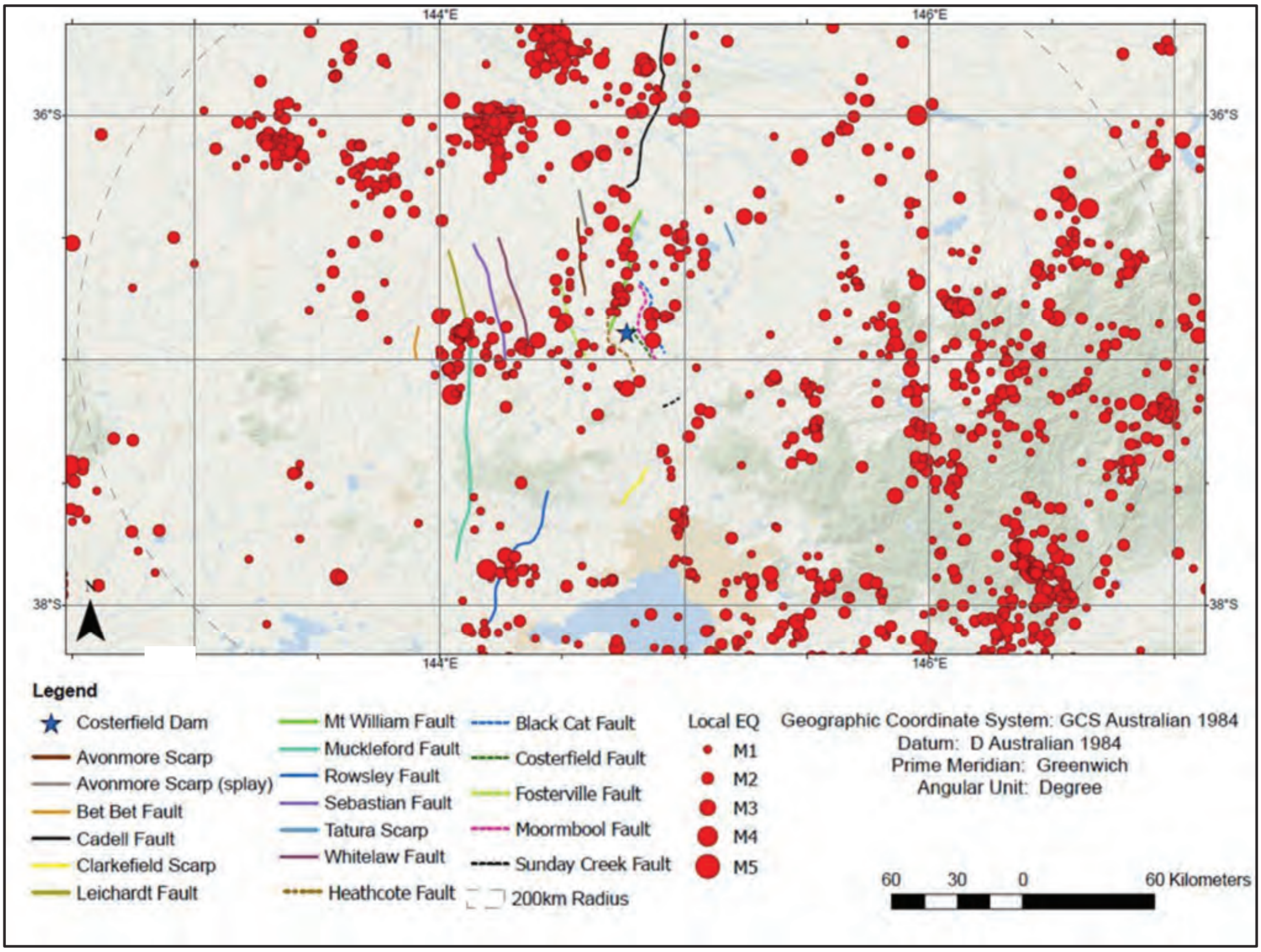
4 REGIONAL TECTONIC SETTING

4.1 Costerfield Tectonic & Fault Background

Australia is a Stable Continental Region (SCR) in terms of its plate tectonic setting and seismicity in accordance with the classification system defined in Allen (2018) **[2]**. Despite such setting, large and potentially damaging earthquakes are not uncommon, and Australia has the highest level of seismicity for any stable continental region, although this is still less than 1% of the activity experienced at active plate boundaries. Six earthquakes which caused surface ruptures have been documented in Australia. Those being 1968 Meckering, 1970 Calingiri, 1979 Cadoux, 1986 Marryat Creek, 1988 Tennant Creek and 2016 Petermann Ranges earthquake. The Petermann Ranges earthquake resulted in a 20 km long fault rupture, with vertical uplift about its centre of almost one metre. Low strain accumulation rates but rapid release rates in earthquakes, relative to plate margin events, suggest strong faults and a high stress drop regime for Australian earthquakes.

Costerfield Gold Mine is located approximately 50 km southeast of Bendigo with the faults surroundings the site as shown below in **FIGURE 1**.

FIGURE 1 EARTHQUAKE LOCATIONS WITHIN 200 km OF COSTERFIELD.

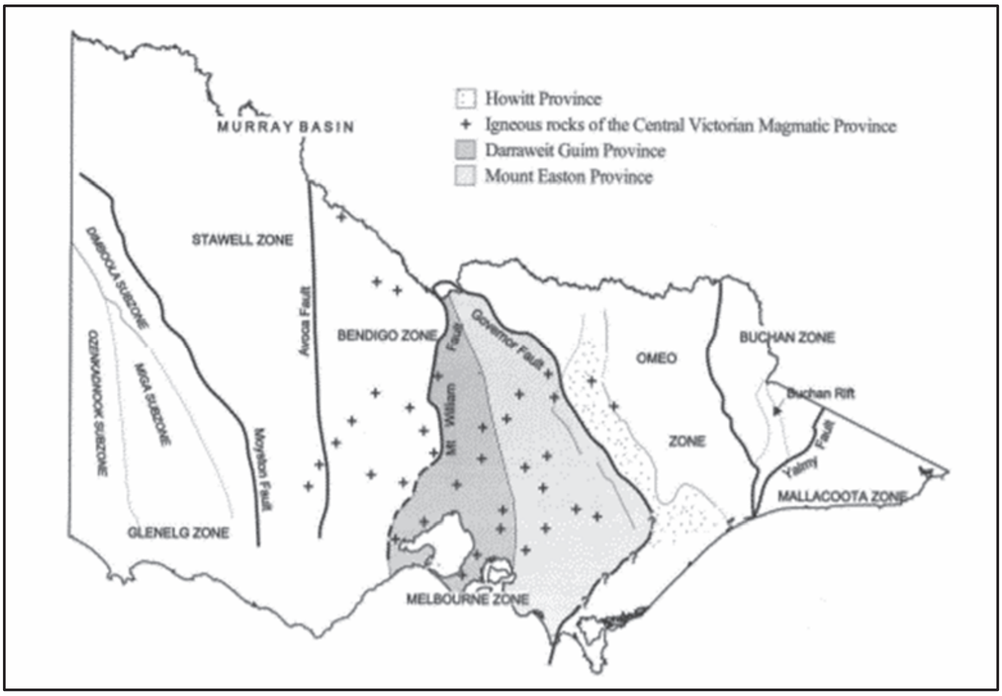


The closest faults to the site are Moormbool Fault (1.7 km east), Costerfield Fault (2.4 km east), Black Cat Fault (6 km east) and Mount William Fault (8 km north), at their minimum distance from the mine site.

4.2 Regional Geological Setting

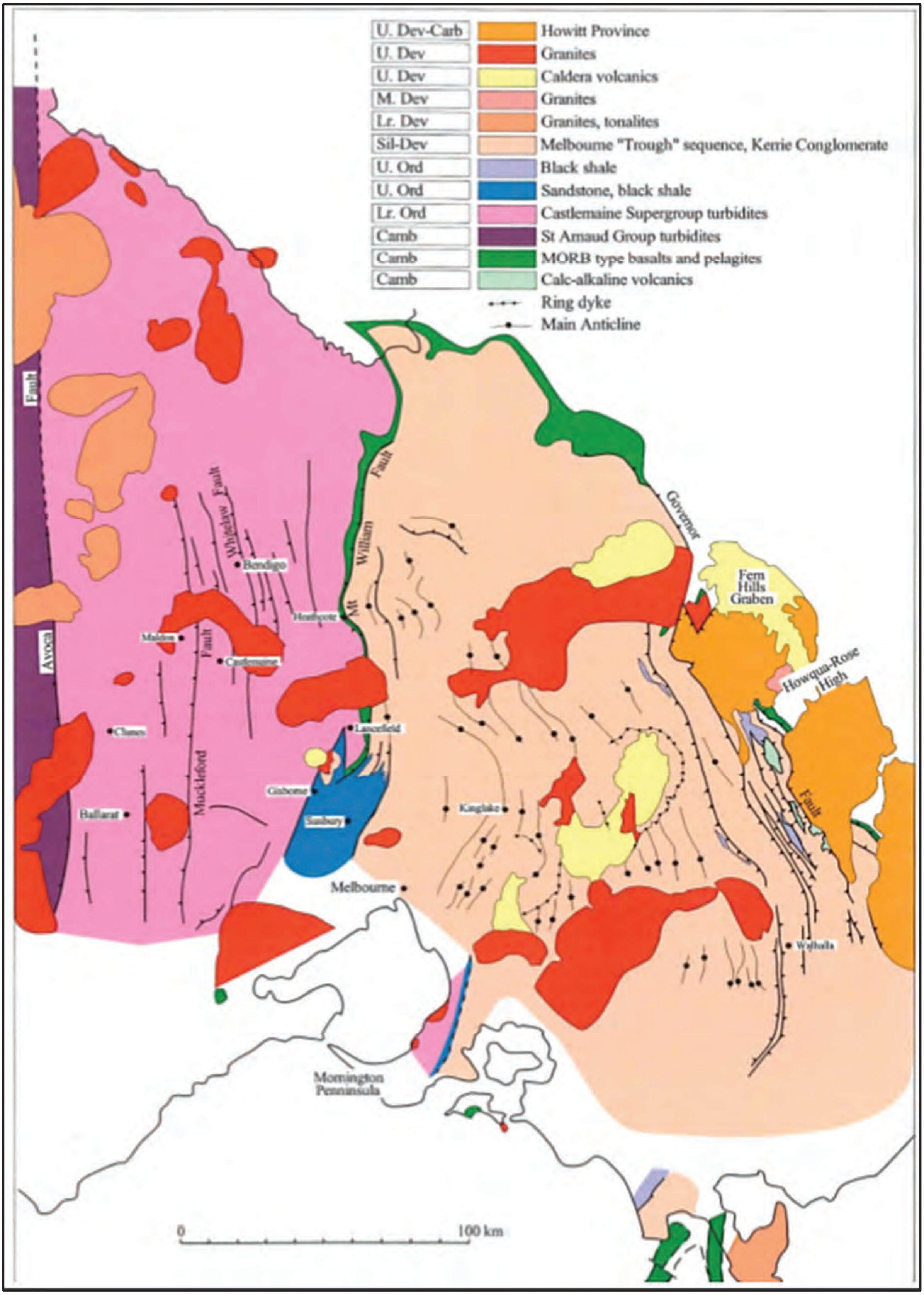
The Costerfield mine site is located within the western side of the Melbourne Structural Zone, which is bounded by the Mount William Fault to the west and the Governor Fault to the east. The Melbourne Zone is divided into two main Provinces, the Darraweit Gum Province to the west and the Mount Easton Province to the east, shown in **MAP 4**.

MAP 4 - MAP OF THE VICTORIAN STRUCTURAL ZONES AND MAIN DEPOSITIONAL AND MAGMATIC PROVINCES [8]**.**



The Palaeozoic basement of Victoria is traversed by several thrust faults, mostly parallel to the structural grain and mostly meridional. The largest faults separate rocks with different ages and structural histories, with seven structural zones defined across Victoria. These faults are mostly high-angle thrusts believed to be rising in listric fashion from a major decollement zone in a Cambrian metavolcanic sequence beneath the sheet of turbidites which constitutes most of the surface exposure **[8]**. The tectonic subdivisions of the Bendigo and Melbourne Zones are shown in **MAP 5.**

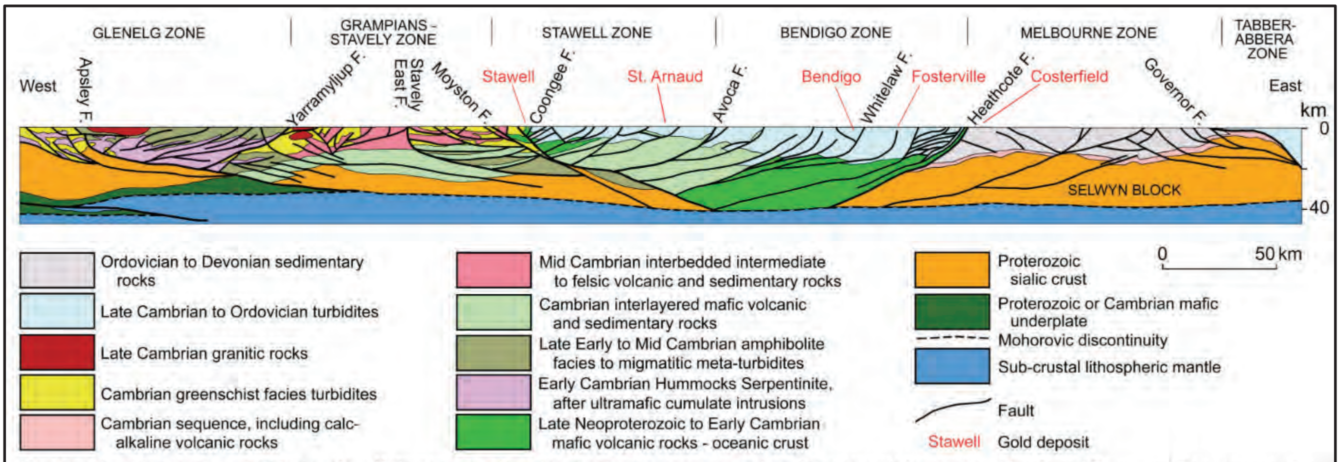
MAP 5 - TECTONIC SUBDIVISIONS OF THE BENDIGO AND MELBOURNE ZONES IN VICTORIA [8].



The Melbourne Zone overlies the Selwyn Block, with geophysical data indicating it to be a northerly extension of the Tyennan and Rocky Cape Blocks in Tasmania. The Melbourne Zone tapers out towards the Murray River and is absent in southern central NSW where the adjacent Bendigo Zone (to the west) and the Tabberabbera Zones (to the east) are contiguous.

A more detailed cross section is shown in **MAP 6**.

MAP 6 - DETAILED GEOLOGICAL CROSS SECTION SHOWING THE MAIN ZONES WEST TO EAST VICTORIA



Geological cross section across the eastern Delamerian and western Lachlan orogens based on deep seismic traverses. Glenelg and Grampians-Stavely zones after Cayley *et al.* (2011); Stawell to Tabberabberan zones after Willman *et al.*, (2010), with minor modifications.

4.3 Instrumental Earthquakes

Note that for discussions in relation to magnitude; the term magnitude refers to M_L.

The recorded instrumental earthquakes surrounding the Costerfield site are provided by G.Gibson (2020-09-09 version). **Appendix A Table A1** lists earthquakes within 40 km of the site with magnitude above 1.0. Note there are only ten events larger than magnitude 3.0. The maximum magnitude listed within 124 km is M_P 4.0 at Seymour. Only one event is closer than 10 km from the site with a magnitude 1.4 on 2017 June 19. It was not reported as felt. The closest event with magnitude 3.0 or higher was an ML 3.1 about 10 km from Costerfield, near Puckapunyal on 1970 Oct 28. It is interesting to note there are only eight events recorded before 1976, when the surrounding seismic network was first installed.

Appendix A Table A2 lists earthquakes with intensities above MMI 2 giving 115 events within 40 km of Costerfield site. The maximum intensity listed within 10 km is MMI 4 in 1970 with a peak ground acceleration of 0.048 g, given its close proximity to Costerfield. Note only six events that could have been felt (MMI 4) all being relatively small nearby events with magnitudes between 3.1 and 4.0. There are 25 larger distant events (earthquakes over ML 5.0) at distances between 200 to 567 kilometres that may have been felt.

5 REGIONAL SEISMOTECTONIC MODEL

One of the critical links between the earthquake database and any calculation for deriving hazard levels is a regional seismotectonic model which should be based on a coherent merging of the total regional database. Thus, it is of paramount importance that the model adopted can provide realistic estimates on the hazards for the site. However, due to inherent uncertainty in any seismotectonic model, three seismic source seismotectonic models will be used with guidance on suitable weights as applied in the NSHA18 project **[11].** The seismotectonic model used in this study was based on the DIM-AUS, AUS6 and NSHM12 (defined by two separate layers the first being the main zones and the second being the background zones) seismic models. These three seismotectonic models were used in the development of the 2018 seismic hazard map by Geoscience Australia **[2][11][14][15].**

AUS6 model is developed as a revised version of the AUS5 model initially developed by Brown and Gibson (2000) which uses geological criteria to identify zones of uniform seismic potential; and then uses historical seismicity to characterise the seismic potential of each zone by means of a-values and b-values of the Guttenberg-Richter earthquake recurrence model together with an estimate of the maximum magnitude of earthquake in each zone [17].

DIM-AUS model was developed based on seismicity, geology, tectonics, magnetics and gravity data were available **[11].**

The NSHM12 model developed by Leonard et al (2013) and has been used to develop the Australian 2012 seismic hazard map (2013) **[6][15].**

Due to the tectonic regime of Australia and stress conditions, the fault mechanism for each source zone is considered as reverse in the analysis software.

FIGURE 2 to **FIGURE 5** respectively show the earthquake source zones in the AUS6 and DIM-AUS seismotectonic models, and the 2 layers of the NSHM12 seismotectonic model. The seismic hazard analyses were carried out for the seismic zones within 400-km radius from the site. The source zones for each seismotectonic model are presented **TABLE 2** to **TABLE 7**, in **SECTION 6** with additional discussion.

FIGURE 2 AUS6 SEISMOTECTONIC MODEL AND THE EARTHQUAKES AROUND THE SITE.

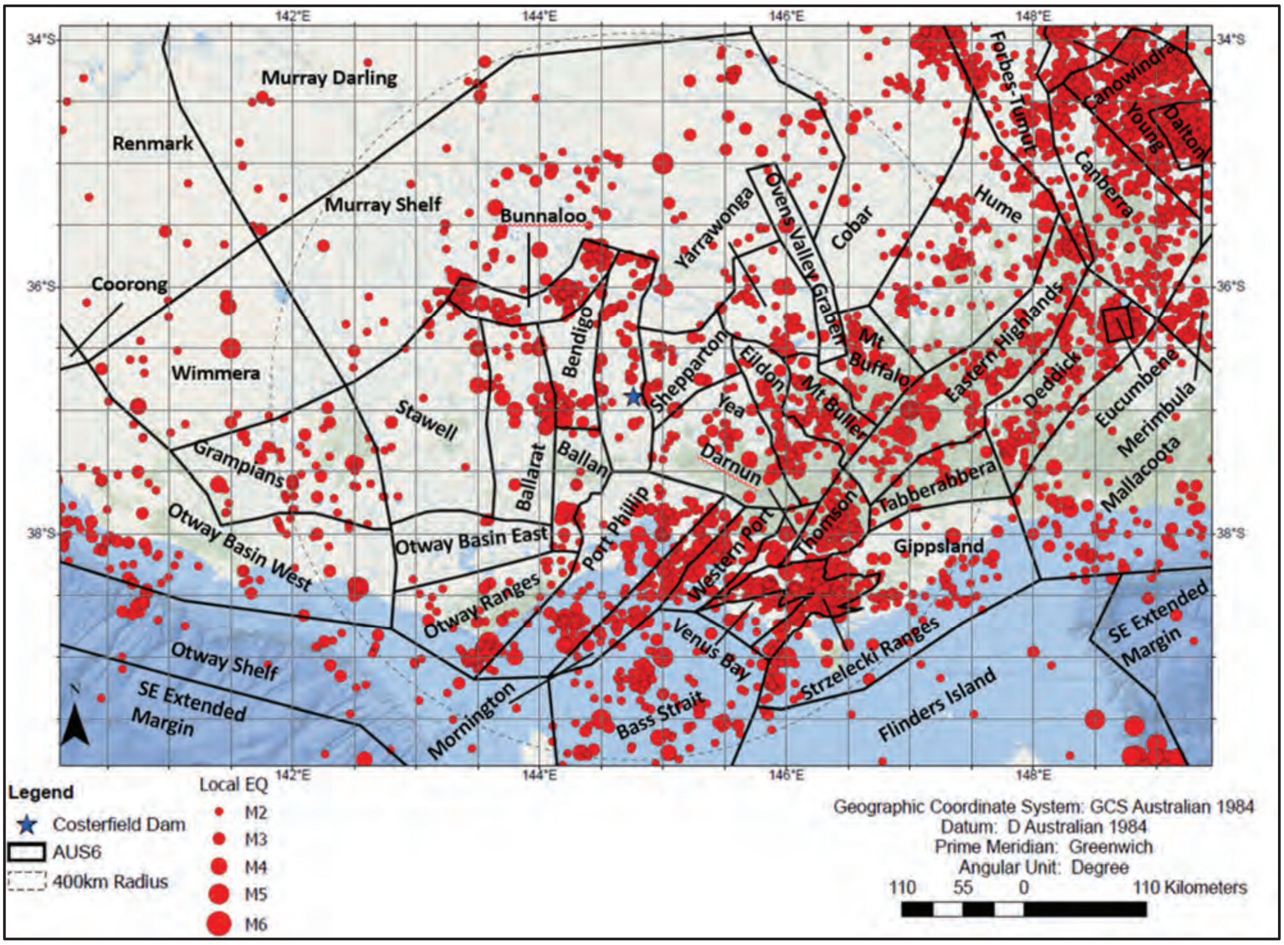


FIGURE 3 DIM-AUS SEISMOTECTONIC MODEL AND THE EARTHQUAKES AROUND THE SITE.

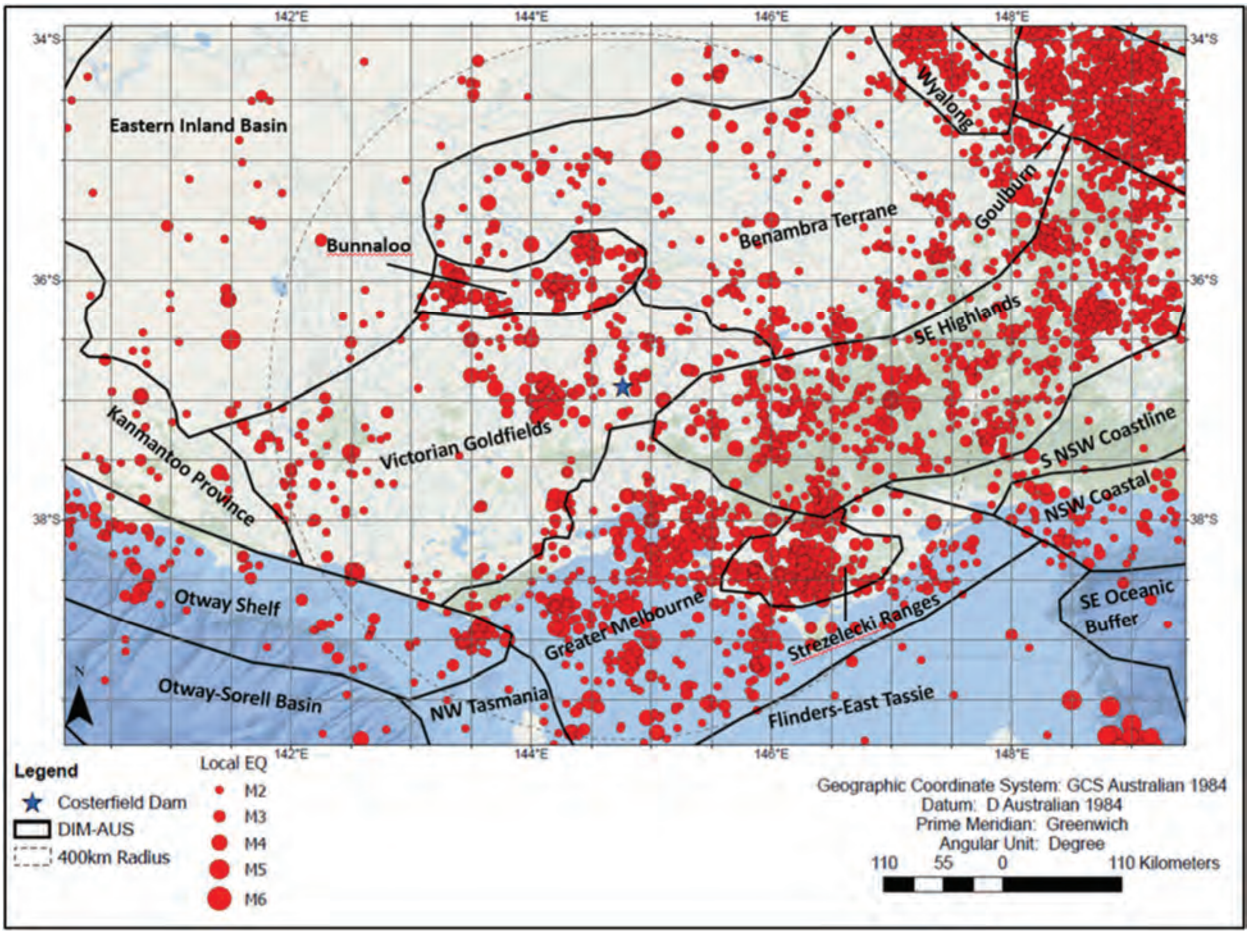


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FIGURE 4 NSHM13 SEISMOTECTONIC MODEL AND THE EARTHQUAKES AROUND THE SITE

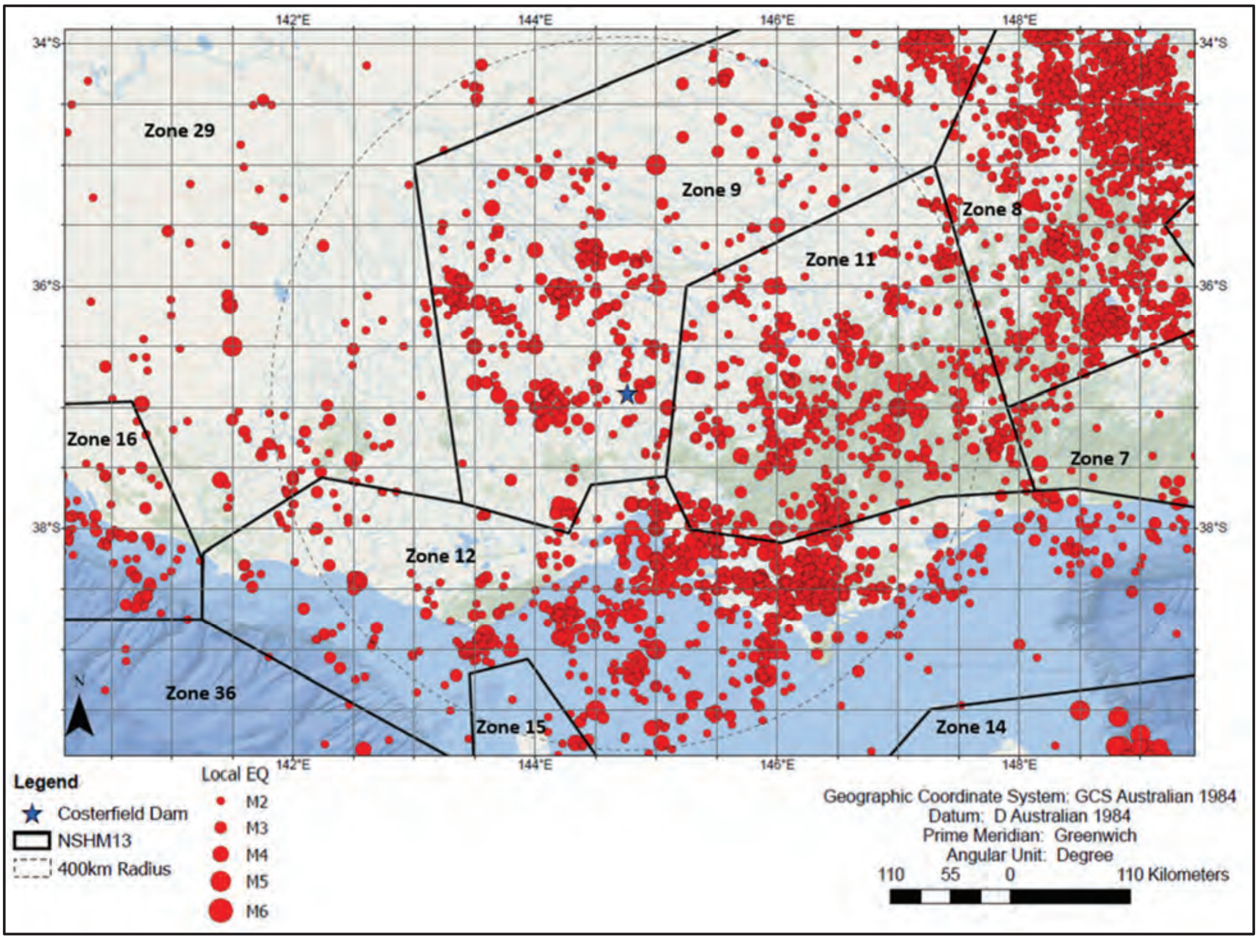

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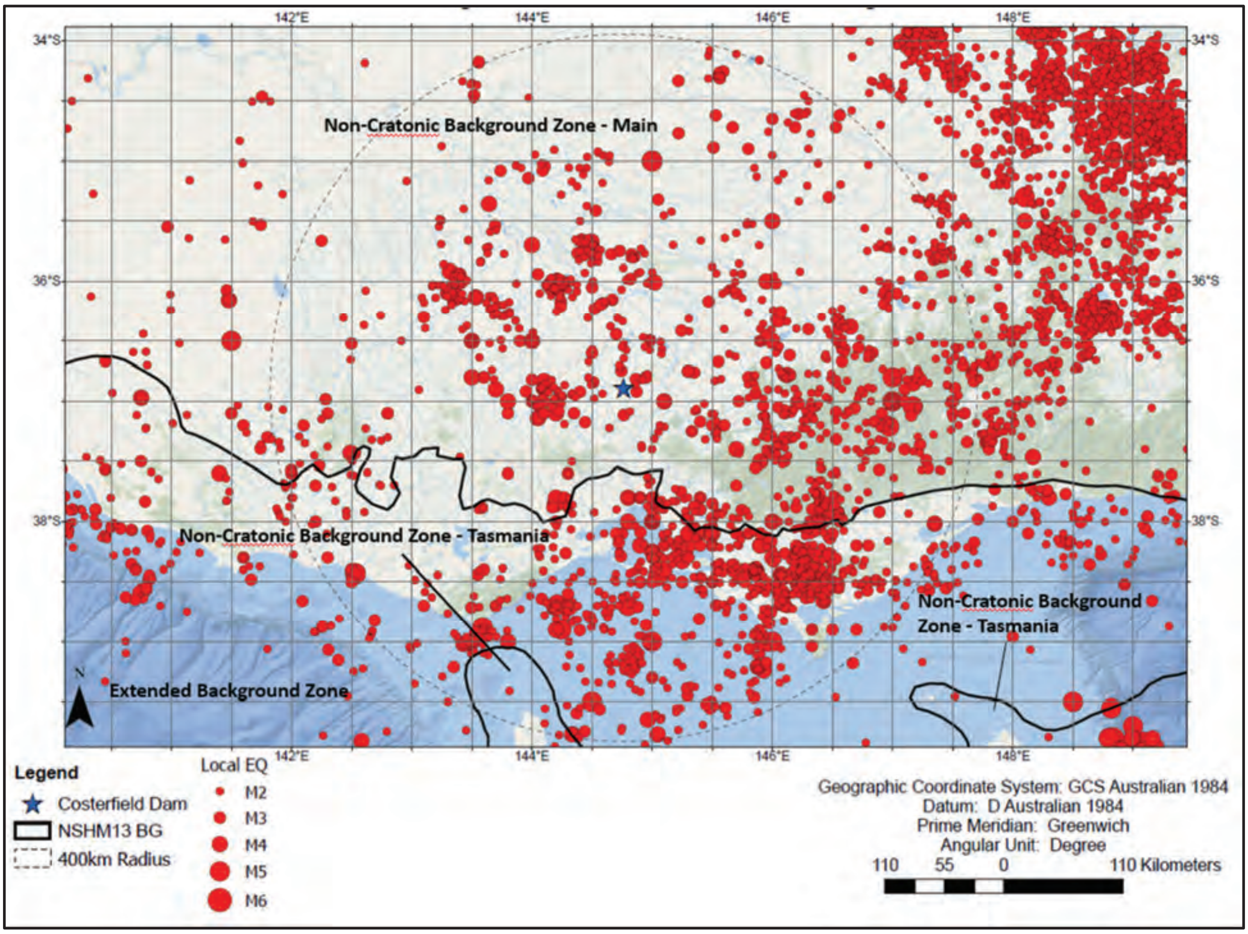
FIGURE 5 NSHM13 SEISMOTECTONIC BACKGROUND MODEL AND THE EARTHQUAKES AROUND THE SITE



To account for epistemic uncertainty three seismotectonic models (with the NSHM13 sub-modelled as 2 layers) are included with varying weights assigned as shown in **TABLE 1** (a full outline of the logic tree is shown in **FIGURE 6**).

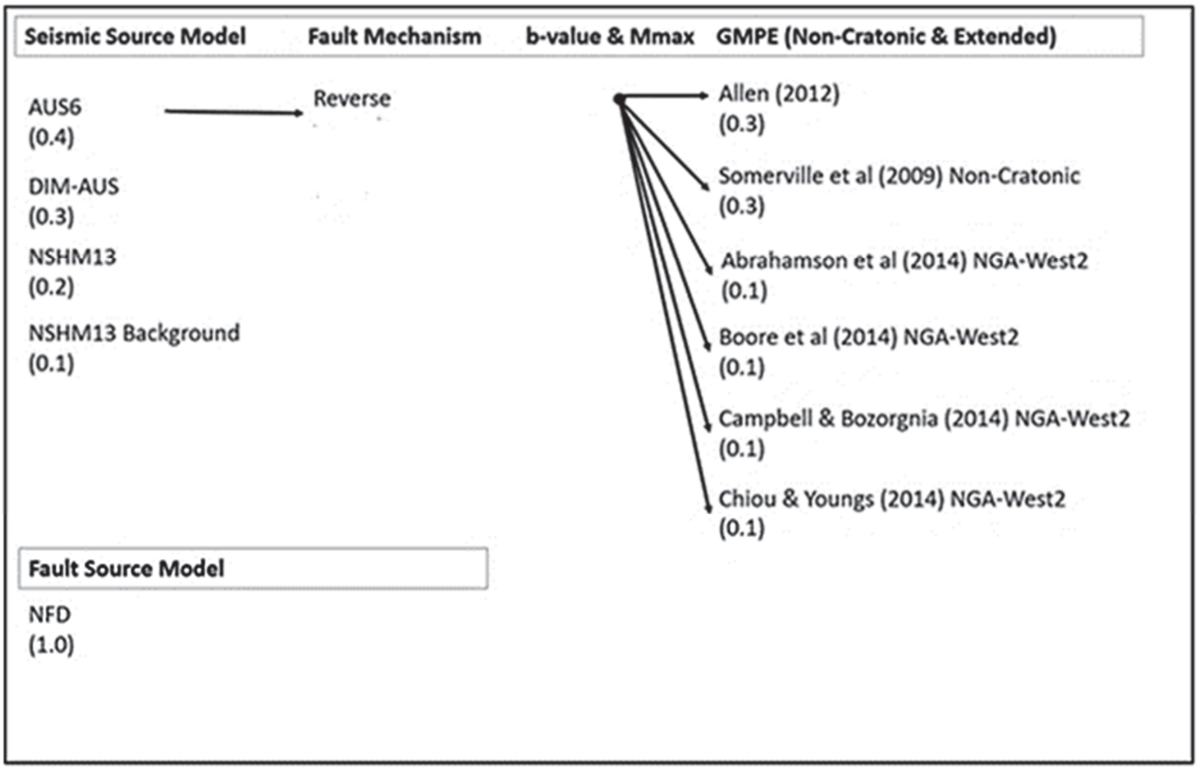
TABLE 1 WEIGHT ADOPTED FOR SEISMOTECTONIC MODELS

Model #	Seismotectonic Model	Weight
1	AUS6 (NSHA-18, 2018)	0.4
2	DIM-AUS (NSHA-18, 2018)	0.3
3a	NSHM13 (NSHA-18, 2018)	0.2
3b	NSHM13 Background (NSHA-18, 2018)	0.1

It is assumed that earthquakes are distributed uniformly with depths in each layer (typically ~2 to 20 km in SCR of Australia). The long-term level of earthquake activity within each source zone is assumed to be uniform, with uniform ratio of small to large earthquakes (b-value) and uniform maximum credible magnitude.

In this study, active fault database developed by Clark (2012) was employed to define the active faults and include them in the seismotectonic model **[1]**. According to this database, there are seventeen active faults within 100 km to the site, closest being 2 km to the east. Thus, the nearby fault sources dominate (particularly Mount William Fault Zone to the west and Black Cat, Moormbool and Costerfield Faults to the east of the site as shown in **FIGURE 1.**

FIGURE 6 LOGIC-TREE DEFINED IN THIS STUDY

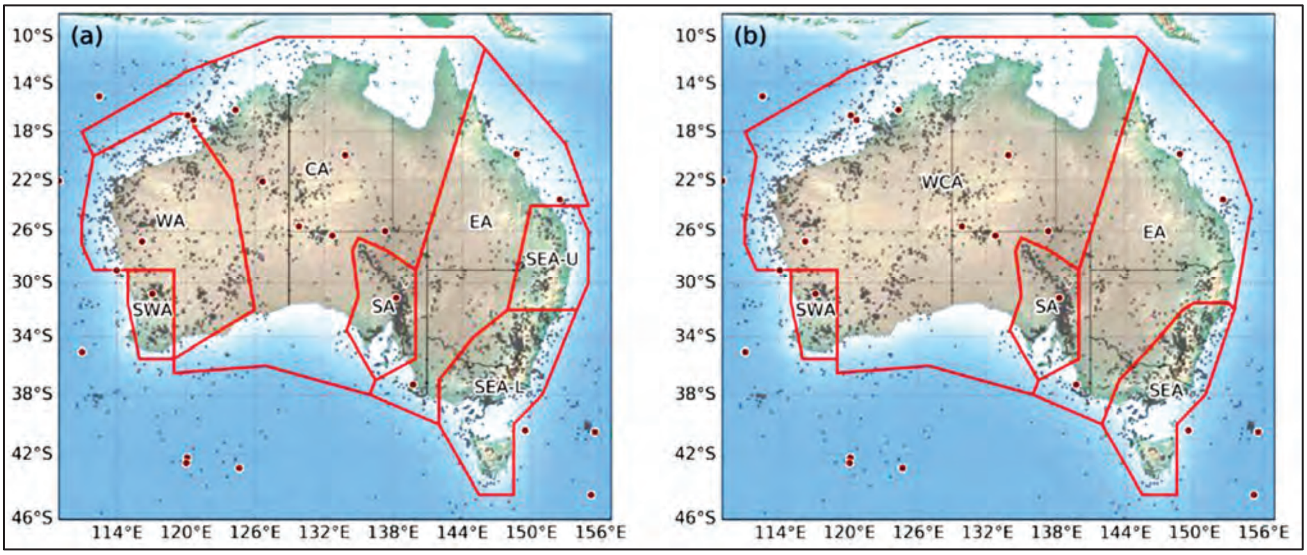


6 EARTHQUAKE MAGNITUDE RECURRENCE

6.1 Quantification of Earthquake Recurrence Parameters

To quantify earthquake magnitude recurrence (EMR), the events were de-clustered, removing dependent events such as foreshocks and aftershocks. Also, the earthquakes corrected for coverage is illustrated by a line showing the variation of magnitude above which all earthquakes are included. According to NSHA18 the final corrected for coverage (also known as Magnitude of completeness or Mc) as presented in **FIGURE 7 (B)** have been applied to our seismic models. For this study we have two different catalogue periods, the SEA (South Eastern Australia) within which Costerfield is located, and the EA (Eastern Australia) with slight variations to corrected for coverage **[2]**.

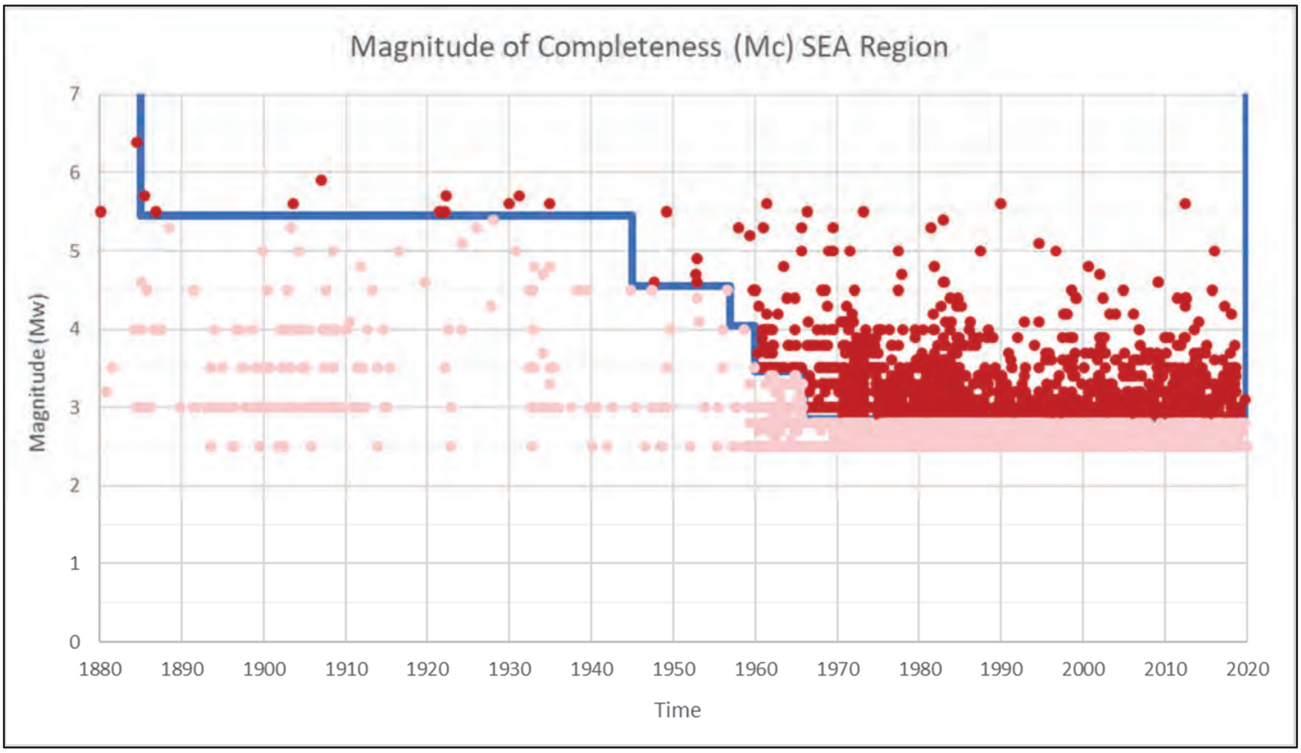
FIGURE 7 (A) INITIAL ZONATION AS DEFINED BY GA AND (B) FINAL ZONATION MODEL AS DEFINED IN NSHA18.



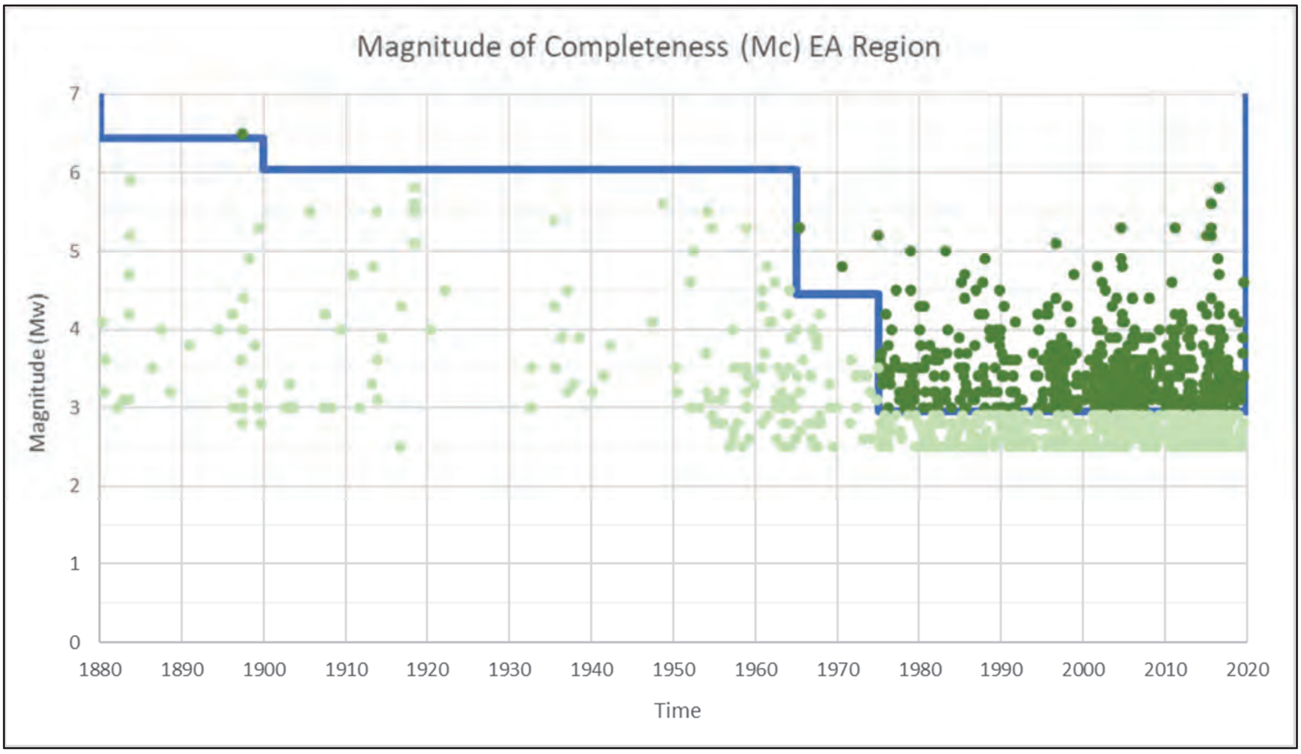
Note: Red dots are earthquakes Mw > 5.6 since 1880. Grey dots are earthquakes Mw > 3.0 since 1977, representing uniform coverage for the Australian continent. Note the subtle differences in labels and zone boundaries for both versions.

The historical account of the monitoring network and the development of the regional seismic monitoring network combined with the complete coverage of SEA and EA are considered in the completeness periods during EMR preparation for each zone. As presented in **GRAPH 1**and **GRAPH** 2 and **GRAPH 3**. These vary for every zone. **GRAPH 1**and **GRAPH 2** are for very large regional zones so the improved seismograph coverage in the local area from 1990 is not reflected, but it is in **GRAPH 3** . The earthquakes shown in both **GRAPH 1**and **GRAPH 2** are split into dark shade (for all earthquakes included in determining earthquake recurrence parameters, i.e. those above the thick blue line representing the Mc for each region) and light shade (for all earthquakes excluded from determining earthquake recurrence parameters, i.e. those below the thick blue line representing the Mc for each region). Earthquakes above the line are assumed to be within the catalogue and are used to perform corrected for coverage analysis using the method described by Allen et al. (2018) **[2]**. Individual zone Mc may vary from zone to zone and from model to model, so these corrected for coverage for SEA and EA regions is illustrative of how the Mc is determined and applied.

GRAPH 1 MAGNITUDE-TIME PLOT FOR EARTHQUAKES WITHIN SEA MC REGION [3]



GRAPH 2 MAGNITUDE-TIME PLOT FOR EARTHQUAKES WITHIN EA MC REGION [3]



The earthquake magnitude recurrence plot is assumed to quantify the long-term average level of activity of the zones. The a-value (number of events exceeding magnitude 0.0 per year) intercepts on the left axis, and b-value is linearly related to the curve's gradient following the Gutenberg-Richter equation:

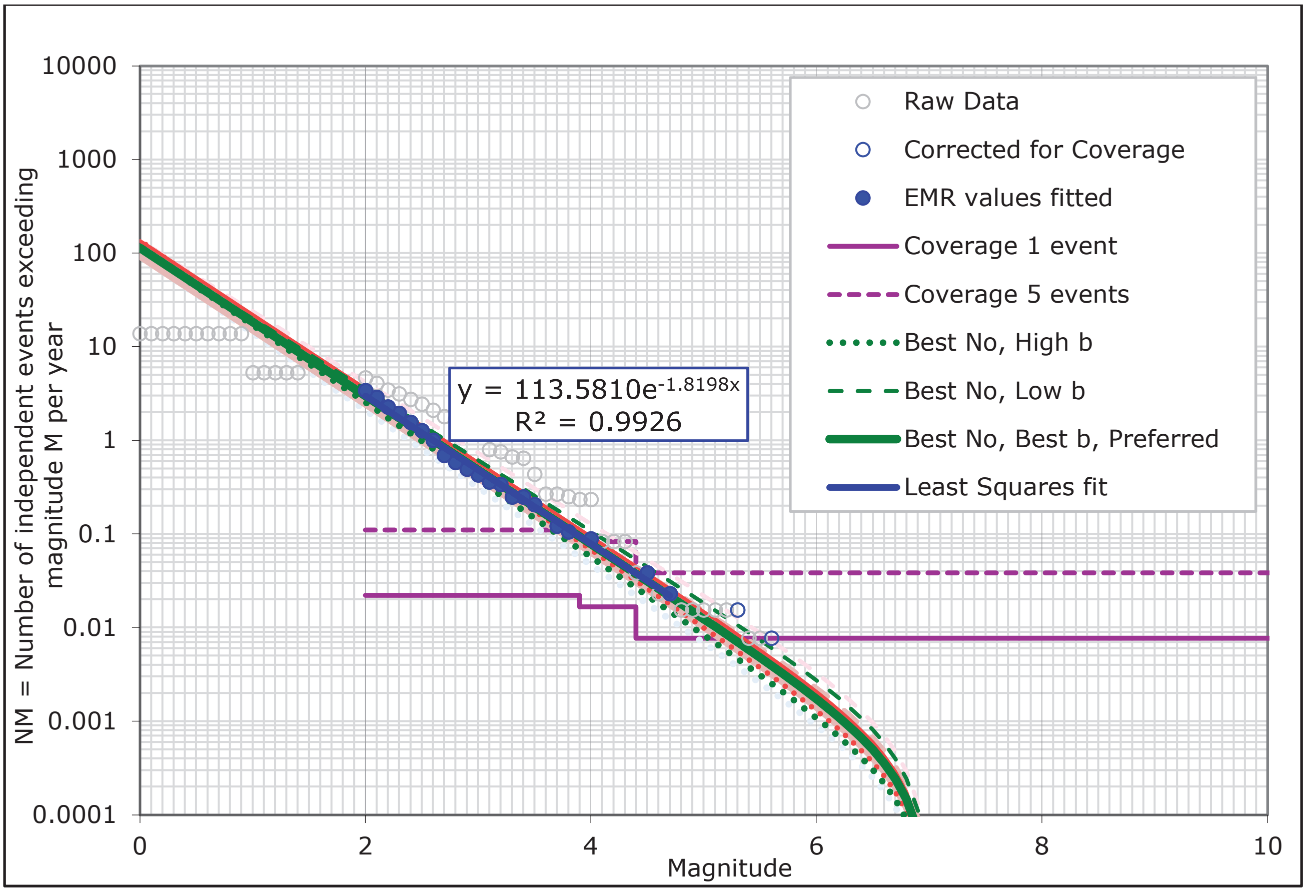
EQUATION 1- GUTENBERG-RICHTER

$$Log\ N = a - bM$$

in which M = earthquake magnitude and N=number of events having a magnitude ≥ M.

Both the *a-values* and *b-values* significantly affect the hazard at the site considered. The values adopted in the analyses were obtained from EMR charts, which are prepared for each zone individually (for example **GRAPH 3**) by considering data presented in Geoscience Australia's latest 2018 NSHA18 Project **[2]**. It should be noted that the *b values* are presented in **TABLE 2** to **TABLE 5**.

GRAPH 3 EARTHQUAKE MAGNITUDE RECURRENCE (Mc) PLOT-COPETON SOURCE ZONE (FROM DIM-AUS MODEL).



The source zones, the area and earthquake magnitude parameters used in the seismotectonic models for DIM-AUS, AUS6 and NSHM12 (main and background models) are presented in **TABLE 2** to **TABLE 5** respectively.

It should be mentioned that an activity from an area source models is removed to avoid double counting when the zone is totally dominated by a relatively large fault.

TABLE 2 QUANTIFICATION OF SEISMIC AREA SOURCE ZONES SURROUNDING THE SITE (AUS6)

Tectonic Fault Mechanism	Code	Area Sources	Area (km^2)	M_{min}	M_{max}	N(0)*	b value
Non-Cratonic	BAL	Ballan	3,208	5.0	7.5	7	0.75
	BEN	Bendigo	3,868	5.0	7.5	16	0.83
	BRT	Ballarat	7,894	5.0	7.5	22	0.75
	BUN	Bunnaloo	3,930	5.0	7.5	91	0.81
	COB	Cobar	138,196	5.0	7.5	50	0.75
	DAR	Darnum	1,373	5.0	7.5	12	0.75
	DED	Deddick	8,632	5.0	7.5	361	1.10
	EHI	Eastern Highlands	12,013	5.0	7.5	116	0.89
	ELD	Eildon	4,524	5.0	7.5	60	0.94
	GPN	Grampians	503	5.0	7.5	58	0.91
	HEA	Heathcote	6,414	5.0	7.5	25	0.75
	HUM	Hume	17,049	5.0	7.5	223	1.03
	MBF	Mt Buffalo	4,252	5.0	7.5	31	0.85
	MBL	Mt Buller	3,369	5.0	7.5	30	0.84
	MDG	Murray Darling	93,978	5.0	7.5	25	0.75
	MYS	Murray Shelf	73,728	5.0	7.5	83	0.80
	OVG	Ovens Valley Graben	3,597	5.0	7.5	20	1
	SPT	Shepparton	4,285	5.0	7.5	15	0.75
	SWL	Stawell	14,146	5.0	7.5	12	0.82
	TAB	Tabberabbera	4,295	5.0	7.5	12	0.75
	TOM	Thomson	2,792	5.0	7.5	37	0.75
	YAR	Yarrawonga	5,282	5.0	7.5	20	0.84
	YEA	Yea	7,732	5.0	7.5	16.3	0.77
Extended	BAS	Bass Strait	23,513	5.0	7.5	80	0.75
	FLI	Flinders Island	78,078	5.0	7.5	84	0.96
	GIP	Gippsland	18,706	5.0	7.5	75	0.85
	MTN	Mornington	3,887	5.0	7.5	25	0.75
	OBW	Otway Basin West	38,703	5.0	7.5	191	0.96
	OTR	Otway Ranges	7,900	5.0	7.5	54	0.85
	OTS	Otway Shelf	73,918	5.0	7.5	467	1.06
	PPL	Port Phillip	11,568	5.0	7.5	26	0.75
	SZR	Strzelecki Ranges	3,739	5.0	7.5	87	0.70
	WNP	Western Port	3,363	5.0	7.5	23	0.77

*denotes the number of events exceeding M0 per year.

TABLE 3 QUANTIFICATION OF SEISMIC AREA SOURCE ZONES SURROUNDING THE SITE (DIM-AUS)

Tectonic Fault Mechanism	Code	Area Sources	Area (km^2)	M_{min}	M_{max}	N(0)*	b value
Non-Cratonic	BNBA	Benambra Terrane	80,790	5.0	7.5	247	0.86
	BNLO	Bunnaloo	8,862	5.0	7.5	379	0.98
	EIBA	Eastern Inland Basins	1,309,110	5.0	7.5	1293	0.88
	SEHI	Southeastern Highlands	59,731	5.0	7.5	850	0.92
	VICG	Victorian Goldfields	61,797	5.0	7.5	114	0.79
Extended	MELB	Greater Melbourne	58,682	5.0	7.5	185	0.75
	OTYB	Otway Shelf	72,488	5.0	7.5	1107	1.03
	STRZ	Strzelecki Ranges	7,480	5.0	7.5	192	0.79

*denotes the number of events exceeding M0 per year.

TABLE 4 QUANTIFICATION OF SEISMIC AREA SOURCE ZONES SURROUNDING THE SITE (NSHM13)

Tectonic Fault Mechanism	Code	Area Sources	Area (km^2)	M_{min}	M_{max}	N(0)*	b value
Non-Cratonic	Z007	ZONE 7	36,860	5.0	7.5	259	1.12
	Z008	ZONE 8	70,674	5.0	7.5	3205	1.01
	Z009	ZONE 9	117,376	5.0	7.5	840	0.93
	Z011	ZONE 11	63,278	5.0	7.5	332	0.83
Extended	Z012	ZONE 12	147,324	5.0	7.5	663	0.81

*denotes the number of events exceeding M0 per year.

TABLE 5 QUANTIFICATION OF SEISMIC AREA SOURCE ZONES SURROUNDING THE SITE (NSHM13 Background)

Tectonic Fault Mechanism	Code	Area Sources	Area (km^2)	M_{min}	M_{max}	N(0)*	b value
Non-Cratonic	NCBM	Non Cratonic Background Zone - Main	2,702,787	5.0	7.5	129,891.8	2.805
	NCBT	Non Cratonic Background Zone - Tasmania	154,809	5.0	7.5	7,787.8	28.05
Extended	EBGZ	Extended Background Zone	3,463,235	5.0	7.7	19,782.7	2.310

*denotes the number of events exceeding M0 per year.

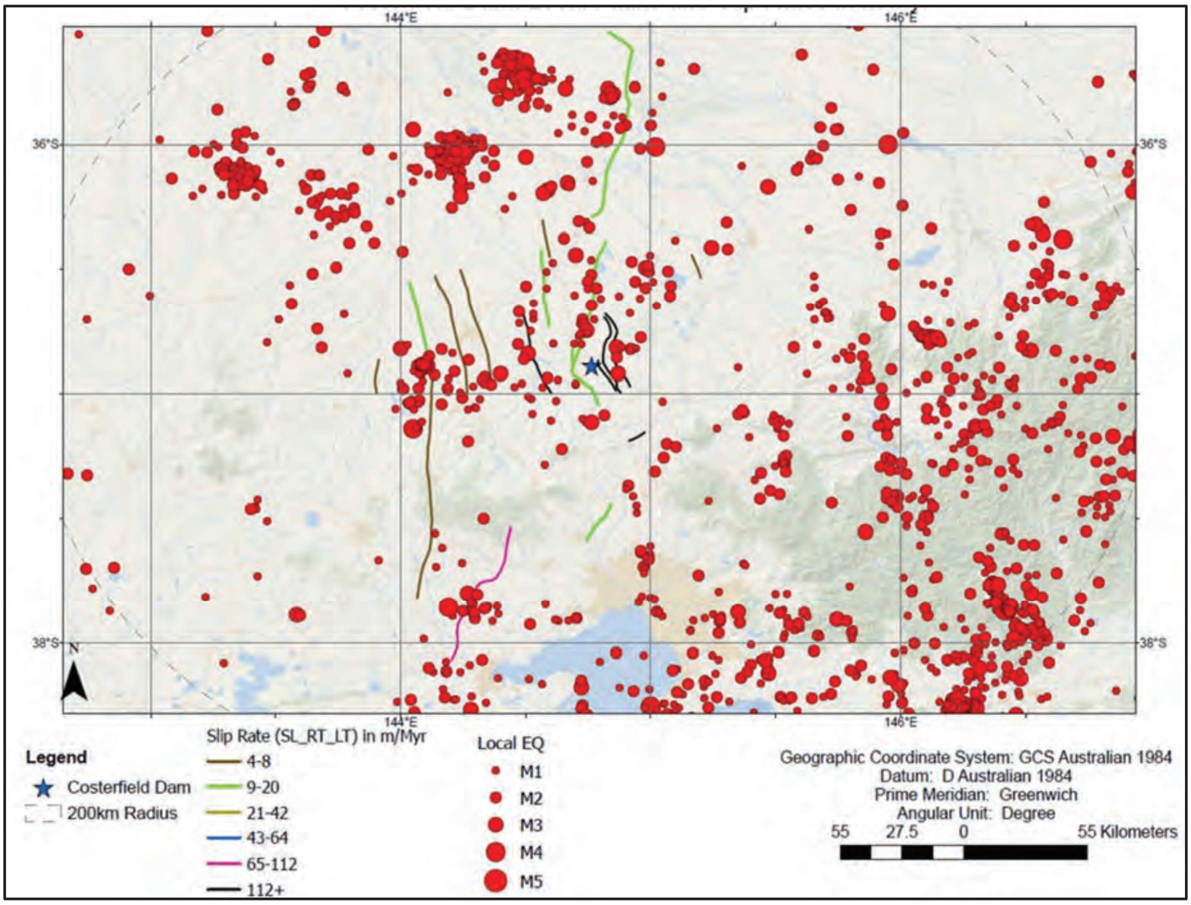
TABLE 6 lists the fault sources within 100 km of the site. **FIGURE 8** shows the long-term slip rate, as defined by GA in the NSHA18 Project for the faults surrounding Costerfield **[2]**. Twelve faults are defined in the GA database, however we have complemented this list with an additional six nearby faults.

TABLE 6 QUANTIFICATION OF SEISMIC FAULT SOURCES SURROUNDING THE SITE

Fault Mechanism	Fault Name	Length (km)	Mmin	Mmax	Closest Distance (km)	Slip Rate* (m/Myr)
Non-Cratonic	Bet Bet Fault	14	5.0	7.0	77	4
	Sunday Creek Fault	9	5.0	6.0	37	5
	Fosterville Fault	49	5.0	7.5	20	5
	Costerfield Fault	19	5.0	6.5	2	5
	Clarkefield Scarp	18	5.0	7.0	58	9
	Sebastian Fault	53	5.0	7.5	34	5
	Avonmore Scarp	34	5.0	7.5	25	19
	Avonmore Scarp (Splay)	16	5.0	6.5	52	5
	Whitelaw Fault	52	5.0	7.5	38	4
	Leichardt Fault	34	5.0	7.5	60	1
	Muckleford Fault	106	5.0	7.5	58	8
	Black Cat Fault	44	5.0	7.5	6	5
	Heathcoat Fault		5.0	7.5		9
	Tatura Scarp	10	5.0	6.0	47	4
	Mount William Fault Zone	150	5.0	7.5	8	13
	Cadell Fault	89	5.0	7.5	68	13
	Rowsley Fault	66	5.0	7.7	78	86
	Moormbool Fault	45	5.0	7.5	3	9

*slip rate – refers to the long-term slip rate as defined by NSHA18.

FIGURE 8 LONG TERM SLIP RATE (M/MYR) ASSIGNED TO INDIVIDUAL FAULTS [3]



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6.2 Minimum and Maximum Magnitude

It is generally accepted that earthquakes smaller than about M5 rarely cause any damage to new well designed and constructed structures, even for shallow earthquakes. If earthquakes are deep, then events smaller than M6 are not expected to cause any significant damage to new well designed and constructed structures.

By restricting the minimum magnitude considered in the estimation of the PGA, the high frequency, high acceleration, low displacement, and short duration motion from small earthquakes is eliminated. The vibrations from small earthquakes are unlikely to have any adverse effect on large structures, but the number of small earthquakes will increase the PGA recurrence estimates.

When computing the ground motion recurrence, it is possible to consider only earthquakes larger than some minimum considered magnitude up to the maximum credible magnitude for each source zone. The minimum magnitude may be chosen depending on the type of structure being considered, and local conditions. Minimum magnitude values may vary in the range from 4 to 6.

A minimum magnitude of 5.0 was used for the remaining calculations in this report. This is considered appropriate for earthquake records and is within the range of events used to derive the ground motion model. This value is also recommended in (ANCOLD, 2019)**[1]**.

The maximum credible magnitude M_{max} is not constrained by the seismicity data, but is constrained by the tectonic setting, specifically the size of active faults, both known and unknown. A value of M7.5 has commonly been used in Australia, where magnitudes up to about M7.1 have been experienced in regions without known active faults. This is probably conservative, but such large events are so rare that the effect of reducing it to 7.3 or 7.2 gives negligible effect on ground motion estimates for the return periods being considered. A maximum magnitude of 7.5 have been considered in this analysis'.

7 GROUND MOTION MODELS

7.1 Review of models

The ground motion resulting from a fault rupture decays with distance because of geometric spreading, scattering and absorption of energy within the surrounding rock. The combined effect of these is the attenuation of seismic wave amplitudes with distance. Earthquake ground motion can be measured as a ground displacement, velocity or acceleration.

Ground motion models are mostly derived from strong ground motion records using statistical techniques. The models are presented in a form generally correlating ground motion to the earthquake magnitude, site to source distance, faulting mechanism and ground type (such as soil, soft rock, hard rock).

Many ground motion models have been published for different geological and tectonic settings, and careful consideration of these settings is required during selection of ground motion prediction models. Such models usually have limitations with respect to earthquake magnitude and distance, which must be considered for selection of appropriate ground motion models in ground motion estimation.

To consider both aleatory variability and epistemic uncertainty between the ground-motion models (GMM), several GMM were used with different weights. The GMM used are the same as those used in the 2018 National Seismic Hazard Assessment (Allen et al., 2018) as shown in **TABLE 7** These GMM are also recommended by ANCOLD (2019) **[1].**

The Allen (2012) and Somerville et al. (2009) GMM were assigned greater weightings of other GMM as they were developed specifically for Australian regions **[1][22].**

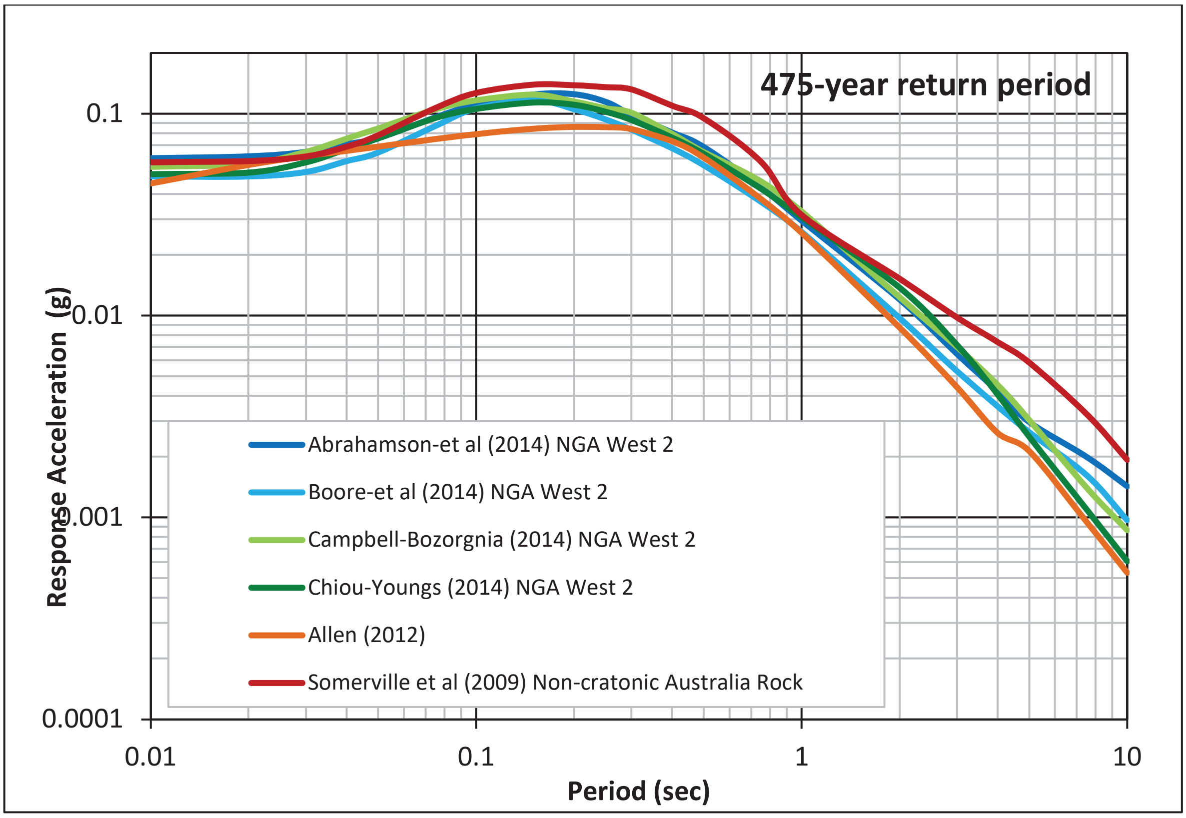
TABLE 7 GROUND MOTION MODELS (GMM) USED – NON-CRATONIC & EXTENDED

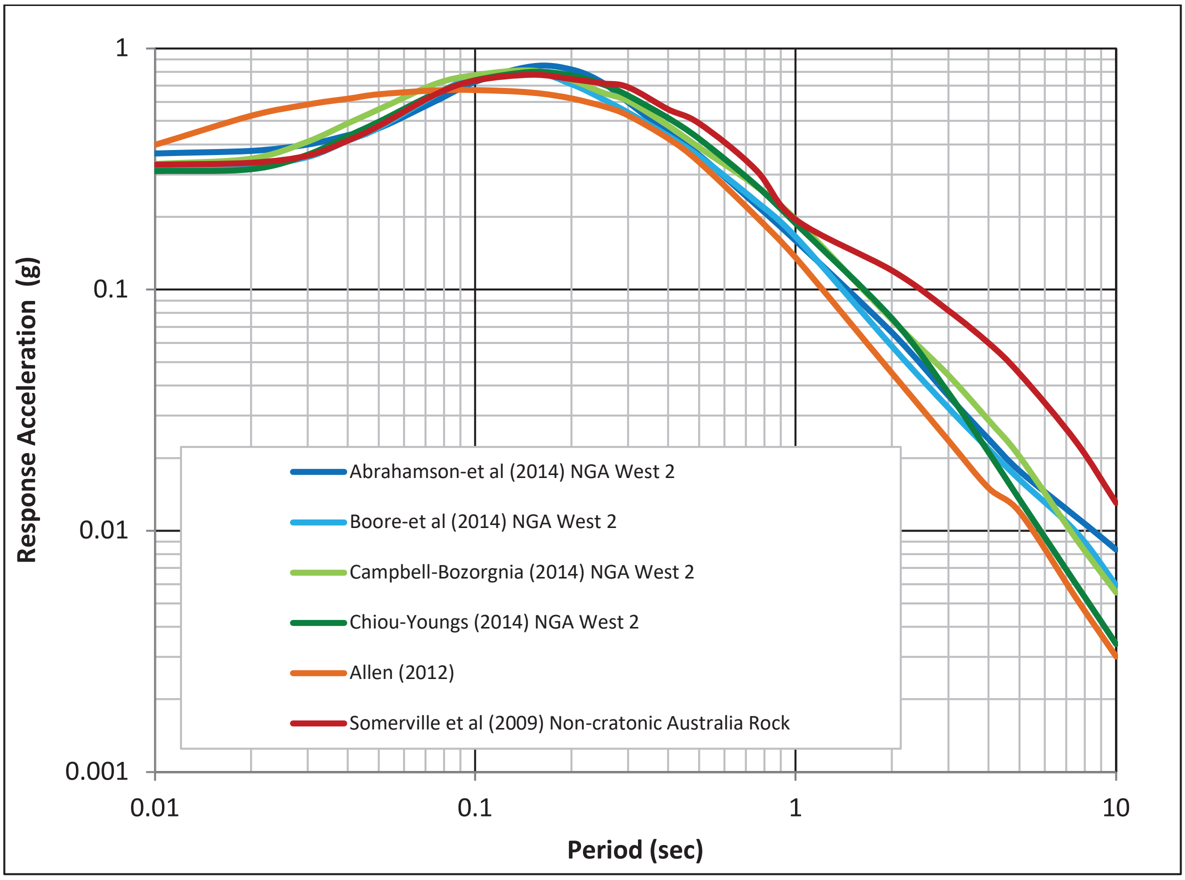
GMM	Assigned Weight	Reference
SE Australia	0.3	Allen, 2012**[16]**
Australia	0.3	Somerville et al., 2009 (Non-Cratonic) **[22]**
NGA West-2	0.1	Abrahamson et al., 2014**[23]**
NGA West-2	0.1	Boore et al., 2014 **[24]**
NGA West-2	0.1	Campbell & Bozorgnia, 2014 **[24]**
NGA West-2	0.1	Chiou & Youngs, 2014 **[24]**

A comparison of the equally weighted Non-Cratonic GMM for the tectonic conditions applied in this study are shown in **GRAPH 4 .** It is more comparative to show each individual GMM in a separate plot for the 475 and 10,000-yr return periods to observe the effect of the individual GMM for the seismic sources. For the 475-year return period the highest PGA is given by Somerville et al (2009) **[22]** Non-Cratonic GMM and the lowest by the Allen (2012) **[16]** GMM, with both these models displaying more variation and set peaks or spikes than the four NGA West2 GMM which are more tightly bounded as they used the same global datasets to produce their relevant GMM. For the 10,00-year return period the highest PGA is given by the Abrahamson et al (2014) GMM and the lowest by the Chiou-Youngs (2014) GMM. The other two NGA West2 GMM are between these two upper and lower bounded GMM. The Somerville et al (2009) Non-Cratonic GMM more closely follows the four NGA West2 GMM especially up to 0.2s period before it then deviates on the upper bound of all GMM. In contrast the Allen (2012) GMM reaches an earlier peak at about 0.07s before it slowly curves on the lower bounds of all other GMM shown here.

The Australian Non-Cratonic GMM give PGA hazard 0.045g and 0.058g for 475-year return period relative to the NGA West2 GMM which give a range between 0.049g and 0.06g. For the 10,000-year return period the Abrahamson et al (2014) GMM gives a PGA hazard 0.37g, with the lowest NGA West2 GMM giving 0.31g from the Chiou-Youngs (2014) GMM. PGA for Australian GMM for this return period are 0.33g and 0.4g for PGA before the Allen GM exceeds all other GMM and then at about 0.07s shifts to the lower bound of all GMM. The Somerville et al (2009) Non-Cratonic GMM instead more slowly follows the four NGA West2 GMM before eventually deviating beyond 0.1s.

GRAPH 4 COMPARISON OF CONTRIBUTION OF VARIOUS NON-CRATONIC GMM FOR 475-YR (UPPER PANEL) AND 10,000-YR (LOWER PANEL) UHS (LOG-LOG)





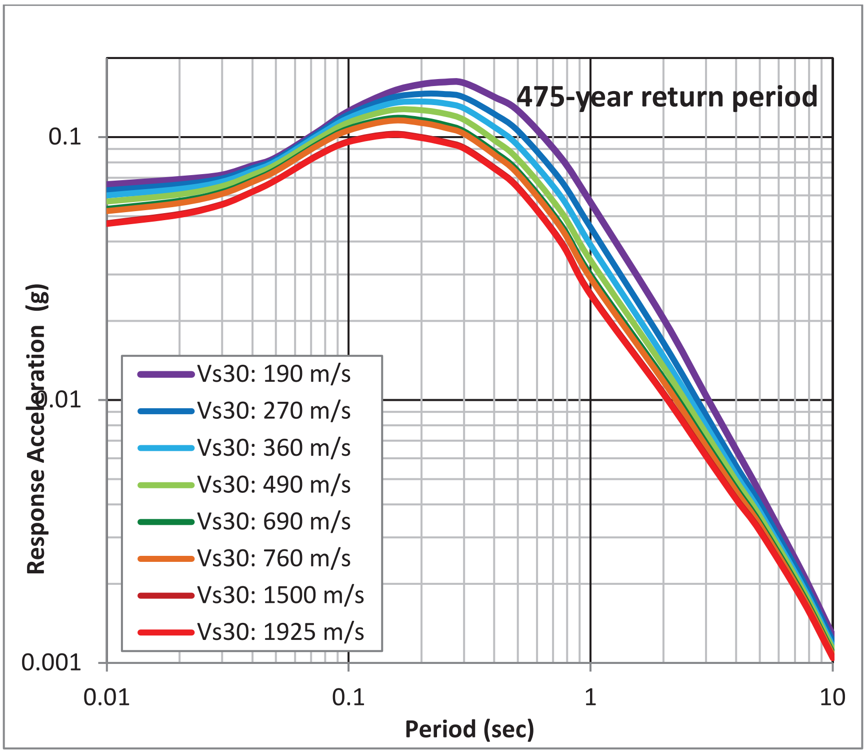
7.2 Site Conditions

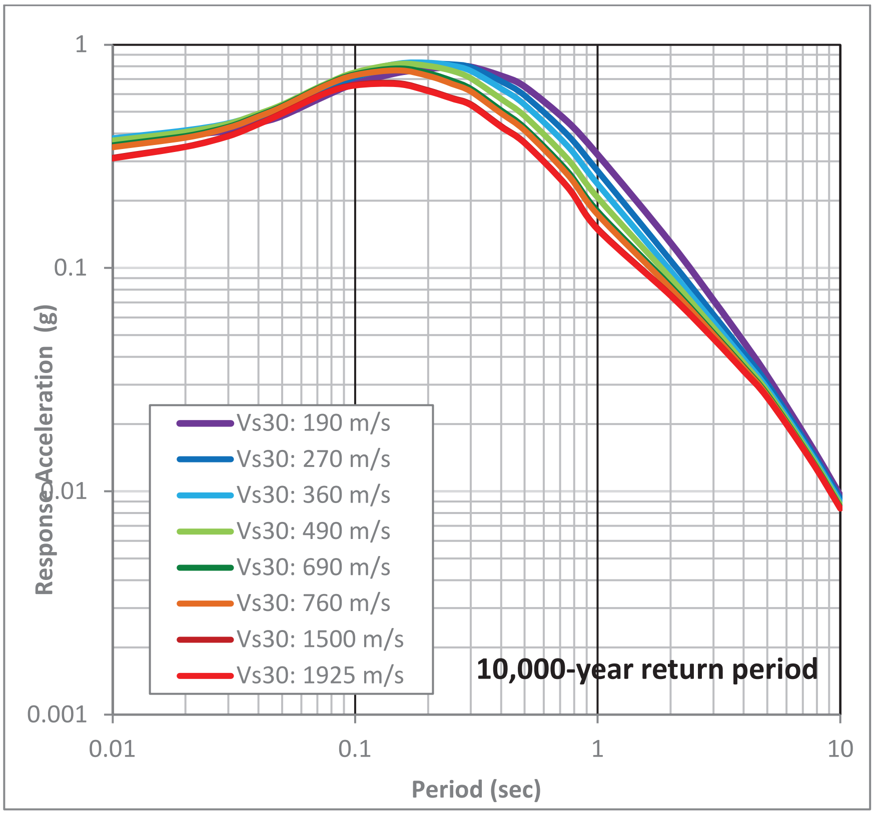
The results of hazard estimation in this study are for bedrock outcrops assuming a shear wave velocity of 760 m/s. Soft sediments amplify the low frequency seismic waves of large earthquakes, but thick layers of soft sediments will reduce the ground motion of smaller local events by absorption of high frequency seismic waves. The average shear-wave velocity in the upper 30 m (Vs_{30}) of 760 m/s is supported by the geological conditions at the site.

A sensitivity plot of a series of Vs_{30} values for the Costerfield site has been prepared in **GRAPH 5**. The selected Vs_{30} values (m/s) have been extracted from McPherson & Hall (2007) which have modified the NEHRP values based on USA soil conditions, to suit our Australian soil conditions with extensive regolith cover in most parts of eastern Australia. These include 190 m/s (lower bound of Site Class D), 270 m/s, 360 m/s (upper bound of Site Class D), 490 m/s (midway of Site Class C), 690 m/s (higher bound of Site Class C or lower bound of Site Class B_C), 1500 m/s (upper bound of Site Class B in NEHRP) and 1925 m/s .

The data are presented for the 475-year and 10,000-year return periods and shows the calculated mean hazard for PGA is 0.066g and 0.369g respectively for the lower bound Vs_{30} value of 190 m/s. For the upper bound Vs_{30} value of 1925 m/s the mean hazard for PGA is 0.0.047g and 0.310g respectively, for the same return periods. This equates to a variation of approximately 29% and 16% from Vs_{30} 190 m/s to 1925 m/s for the 475 year and 10,000-year return periods, respectively.

GRAPH 5 SENSITIVITY OF V_{S30} (M/S) VALUE TO THE COSTERFIELD SITE (475 YEARS UPPER PANEL; 10,000 YEARS LOWER PANEL)





8 SEISMIC HAZARD ANALYSIS

The PSHA is recommended at Costerfield as it allows the treatment of uncertainty in general and not only the worst possible scenario.

The PSHA method was used in this study for calculations of ground motion. This is based on the methodology of Cornell, (1968). In this PSHA method, ground motion probabilities are numerically integrated to produce the annual frequency of exceedance for any ground motion variable of interest. The seismic hazard analysis is carried out using EZ-FRISK™ software [4].

EZ-FRISK™ uses the standard methodology for seismic hazard analysis [4]. Multiple attenuation equations can be specified by the user for one run of the program, and the results can be used to plot sensitivity of hazard to attenuation equation and/or to plot results as uniform hazard spectra (over a range of ground motion frequencies).

The seismic-hazard calculations can be represented by the following equation, which is an application of the total-probability theorem.

Equation 2 - TOTAL-PROBABILITY THEOREM

$$H(a) = \sum V_i \iint P[A > a|m,r] f_{M1}(m) f_{R1|M1}(r,m) dr dm$$

In which,

- *H(a)* is hazard, which is the annual frequency of earthquakes that produce a ground motion amplitude A higher than a;
- *A* is amplitude, which may represent PGA, velocity or displacement, or spectral pseudo-acceleration for a given frequency;
- v_i is the annual rate of earthquakes (with magnitude higher than some threshold M_{oi}) in source i;
- $f_{Mi}(m)$ and $f_{Ri|Mi}(r;m)$ are the probability density functions on magnitude and distance, respectively;
- $P[A > a|m, r]$ is the probability that an earthquake of magnitude m at distance r produces a ground-motion amplitude A at the site that is greater than a;
- The summation in **Equation 2** extends over all sources, i.e. over all faults and areas.

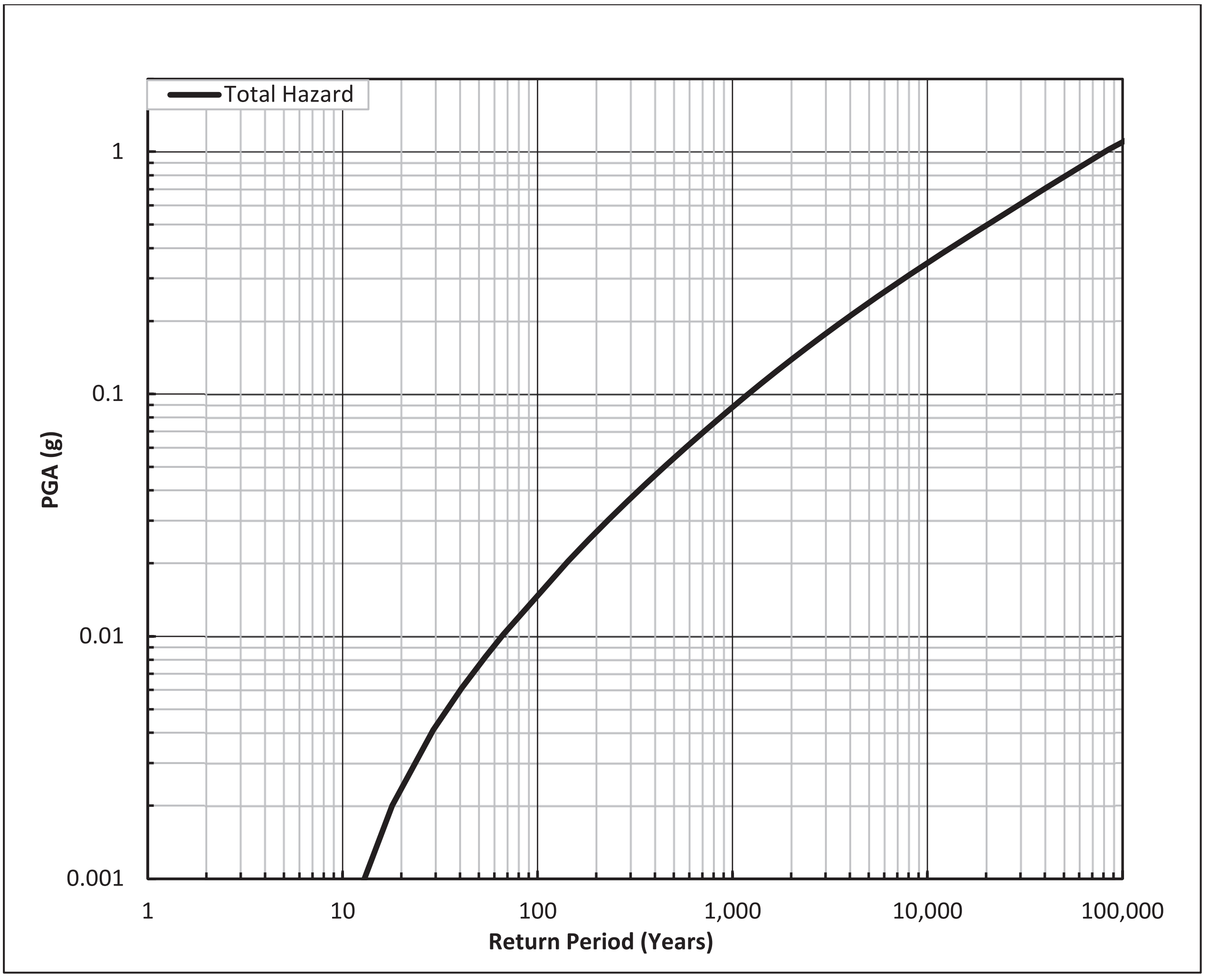
Seismic sources may be either faults or area sources; the specification of source geometries and the calculation of $f_{Ri|Mi}$, are performed differently for these two types of sources. Detailed description of the probabilistic seismic hazard analysis used in this study is found in the EZ-FRISK™ manual **[4].**

9 RESULTS

9.1 Hazard Curves

The principal output of the PSHA is the seismic hazard curve, which provides the probability of exceedance of a particular ground motion intensity measure, obtained from the integral described above. **FIGURE 9** presents the seismic hazard curve for the PGA which were obtained from this site-specific seismic hazard study. The weighted total hazard curve is shown.

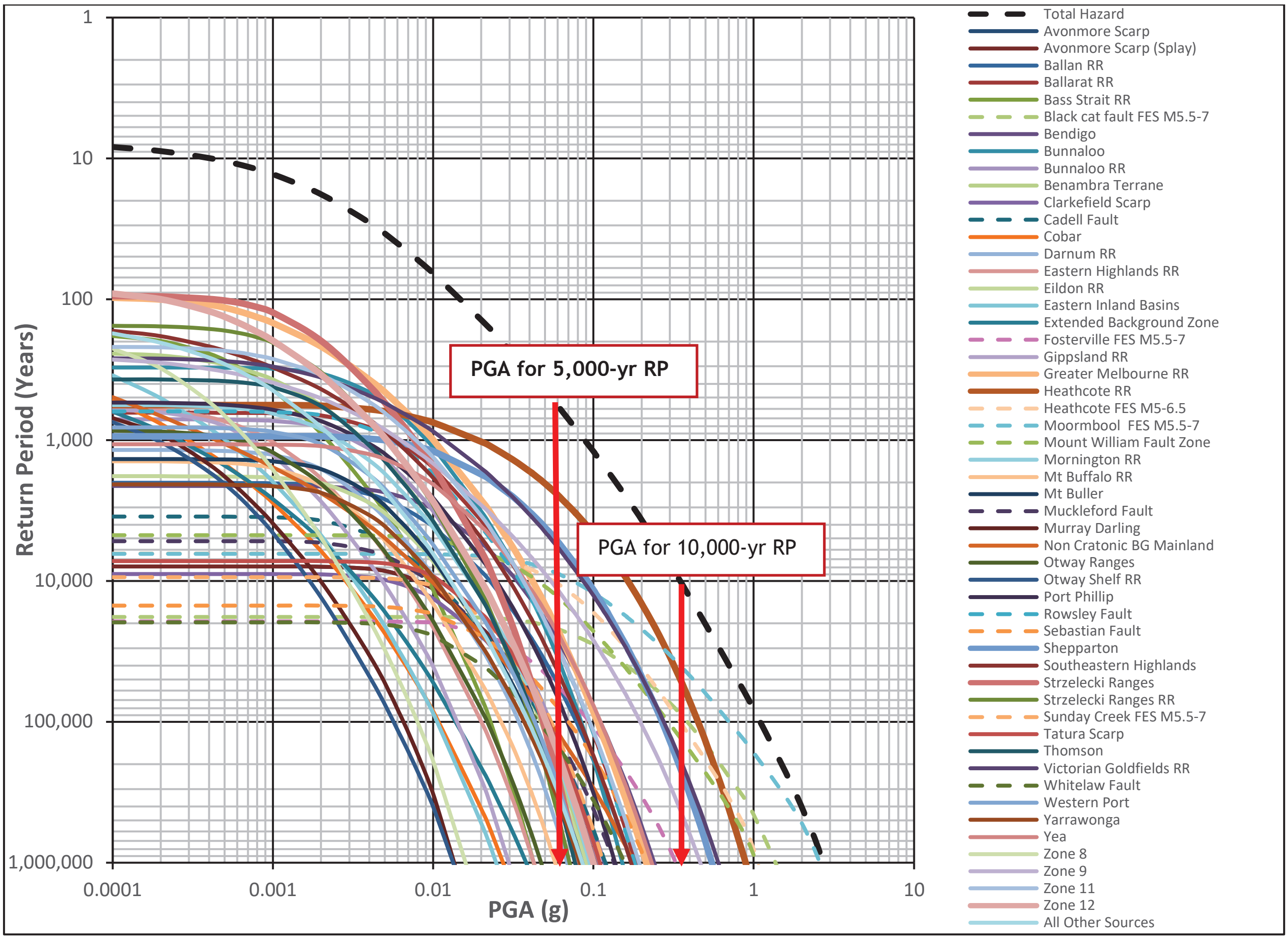
FIGURE 9 SITE SPECIFIC SEISMIC HAZARD CURVE FOR PGA



9.2 Source Contributions

The contribution of the various seismic sources (areas or faults) of each model is shown in **FIGURE 10**. The total hazard curve for the site at any given Annual Exceedance Probability (AEP) is indicated by the black solid curve. The other curves are dashed for models and dashed for fault sources. The red straight lines atop this plot are to show how to read the PGAs corresponding to a 5000-year return period (return period =1/AEP) and a 10,000-year return period. The zones that have the greatest contribution in the total hazard, are presented with thick lines such as Heathcote (Brown line). Faults are presented with dash lines.

FIGURE 10 TOTAL HAZARD AND CONTRIBUTIONS FROM INDIVIDUAL SOURCE ZONES FOR SPECTRAL ACCELERATION AT ZERO PERIOD (PGA).



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9.3 Uniform Hazard Response Spectra

The uniform hazard response spectra (UHS) for return periods of 475 years, 1000 years, 2000 years, 5000 years and 10,000 years have been computed at 5% critical damping. The UHS results for a Vs_{30} of 760 m/s (rock) for the Costerfield site are summarised in
TABLE 8, and shown graphically in **FIGURE 11** (linear-linear) and **FIGURE 12** (log-log).

TABLE 8 PROBABILISTIC RESPONSE SPECTRA FOR DIFFERENT RETURN PERIODS – COSTERFIELD

Period (s)	Spectral accelerations (g) for different return periods				
	475 yr	**1000 yr**	**2000 yr**	**5000 yr**	**10,000 yr**
0.01	0.052	0.088	0.138	0.238	0.347
0.02	0.056	0.095	0.150	0.261	0.384
0.03	0.061	0.104	0.166	0.289	0.424
0.04	0.068	0.117	0.186	0.325	0.477
0.05	0.074	0.129	0.207	0.361	0.527
0.075	0.093	0.163	0.260	0.450	0.654
0.1	0.106	0.184	0.292	0.504	0.730
0.15	0.116	0.196	0.309	0.531	0.769
0.2	0.113	0.189	0.294	0.502	0.726
0.25	0.109	0.177	0.274	0.463	0.669
0.3	0.103	0.166	0.254	0.429	0.616
0.4	0.086	0.135	0.203	0.341	0.493
0.5	0.072	0.114	0.171	0.285	0.412
0.75	0.046	0.072	0.107	0.180	0.263
1	0.029	0.046	0.069	0.116	0.173
2	0.012	0.020	0.031	0.054	0.081
3	0.007	0.011	0.018	0.033	0.050
4	0.004	0.008	0.013	0.023	0.036
5	0.003	0.006	0.010	0.018	0.027
7.5	0.002	0.003	0.005	0.010	0.014
10	0.001	0.002	0.003	0.006	0.008

FIGURE 11 UHS PLOT FOR DIFFERENT RETURN PERIODS WITH 5% DAMPING (LINEAR-LINEAR).

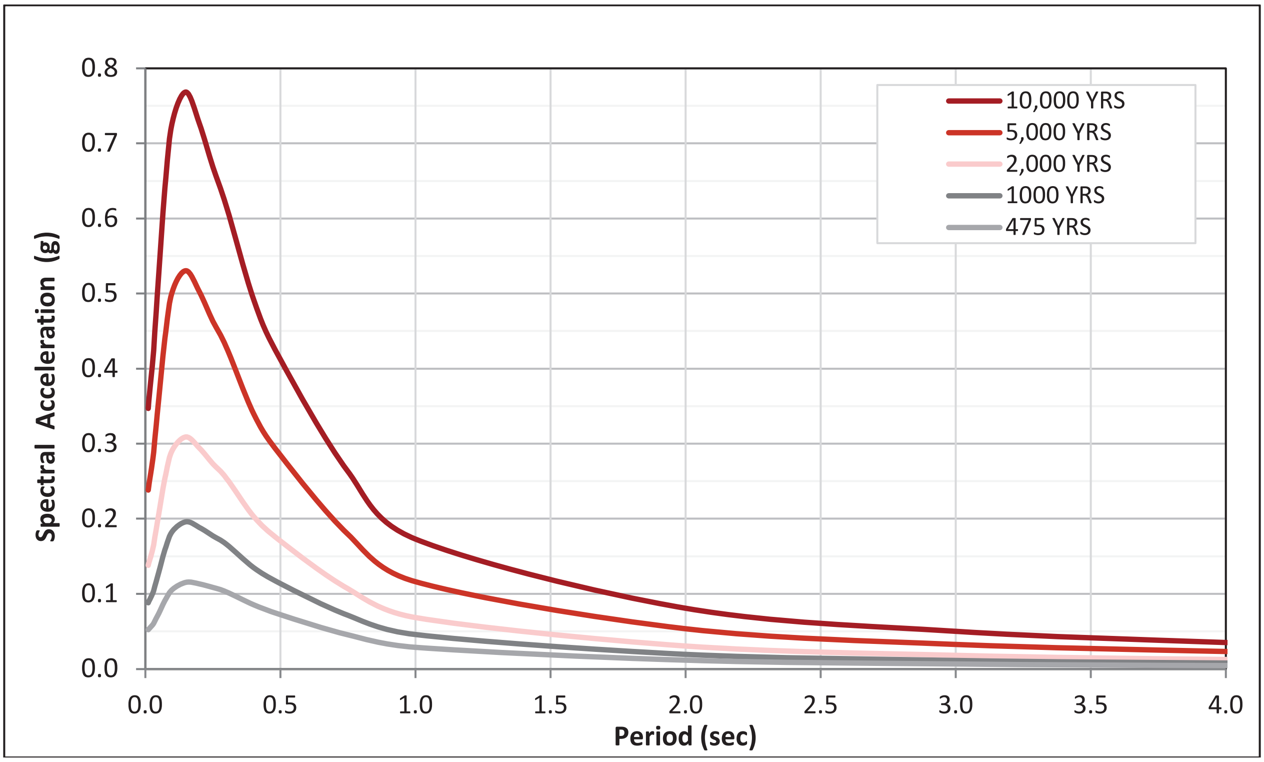
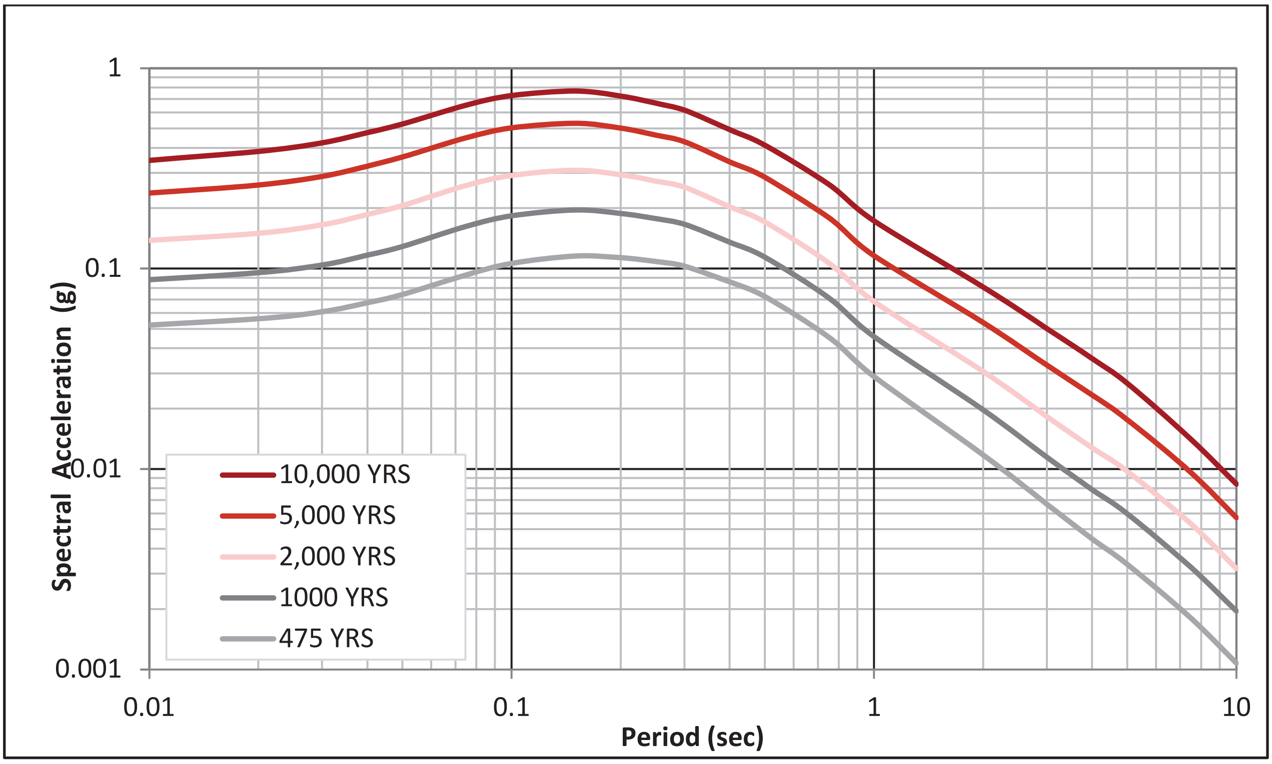


FIGURE 12 UHS PLOT FOR DIFFERENT RETURN PERIODS WITH 5% DAMPING (LOG-LOG).



9.4 Epistemic Uncertainty

FIGURE 13 to **FIGURE 17** present the calculated UHS (in log-log scale) for each return period seismic event. Response spectra for the mean, 50th (median) and 85th fractiles are shown in these figures. There were insufficient data to produce the 95th fractiles.

The lower and upper fractiles represent the estimated degree of uncertainty as to where the true hazard for the site lies based on the model that has been used in this study.

FIGURE 13 FRACTILES OF THE UNIFORM HAZARD SPECTRA FOR THE 475-YEAR RETURN PERIOD (LOG-LOG)

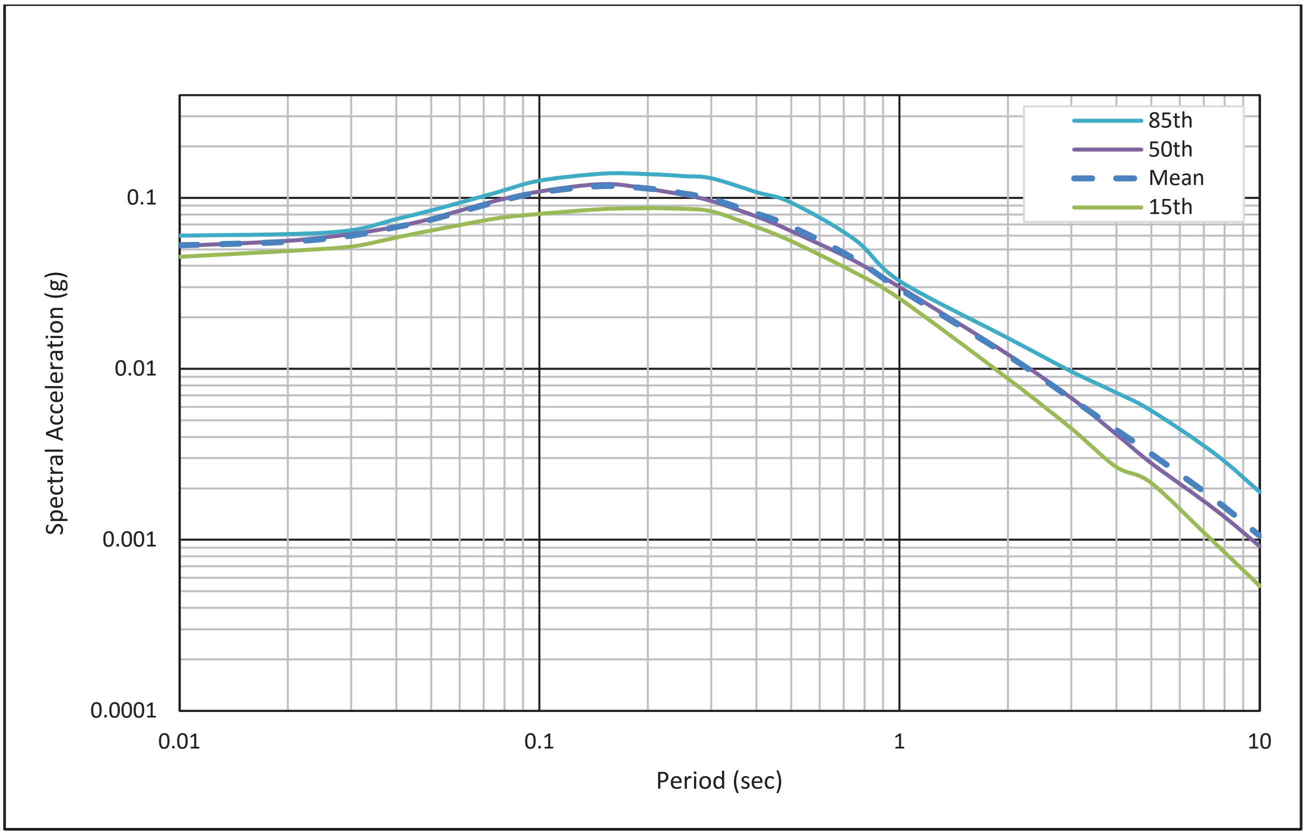


FIGURE 14 FRACTILES OF THE UNIFORM HAZARD SPECTRA FOR THE 1000-YEAR RETURN PERIOD (LOG-LOG)

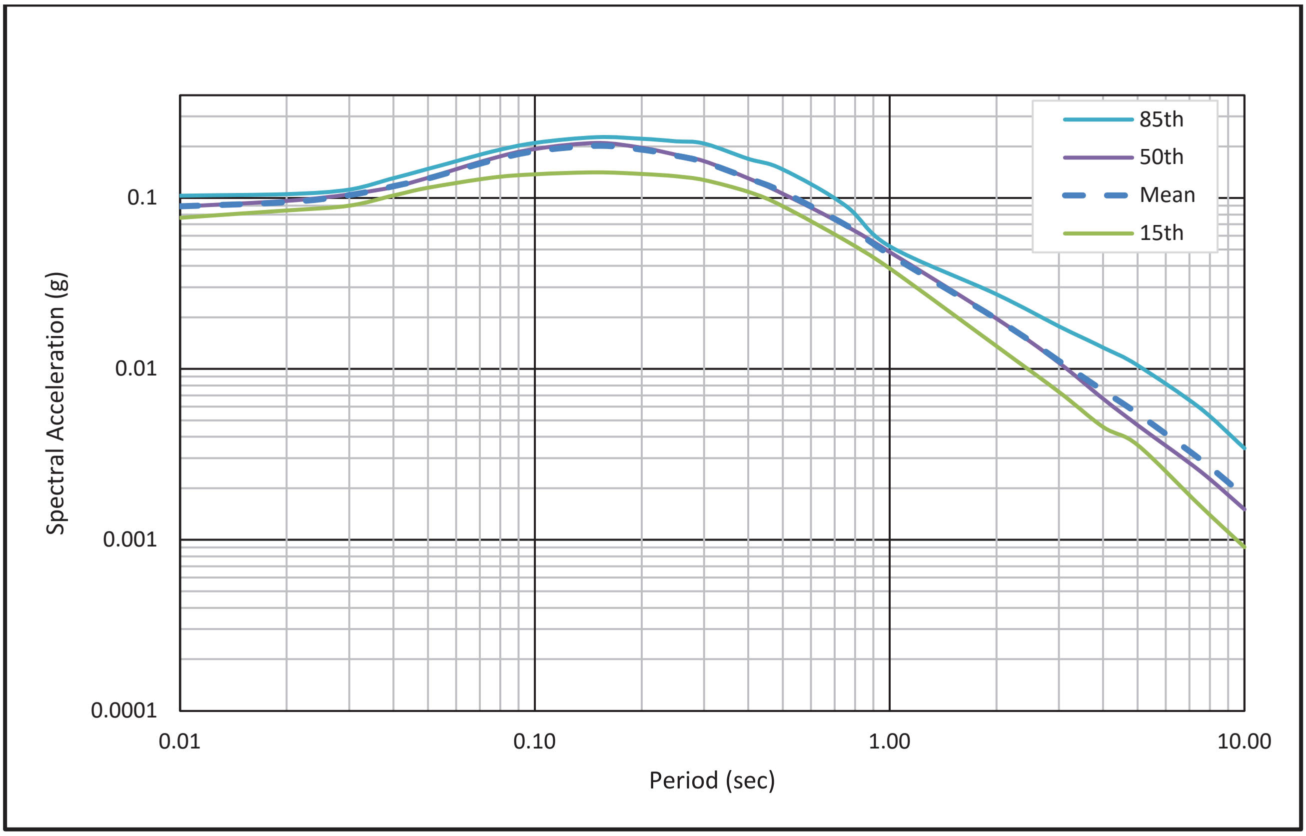


FIGURE 15 FRACTILES OF THE UNIFORM HAZARD SPECTRA FOR THE 2000-YEAR RETURN PERIOD (LOG-LOG)

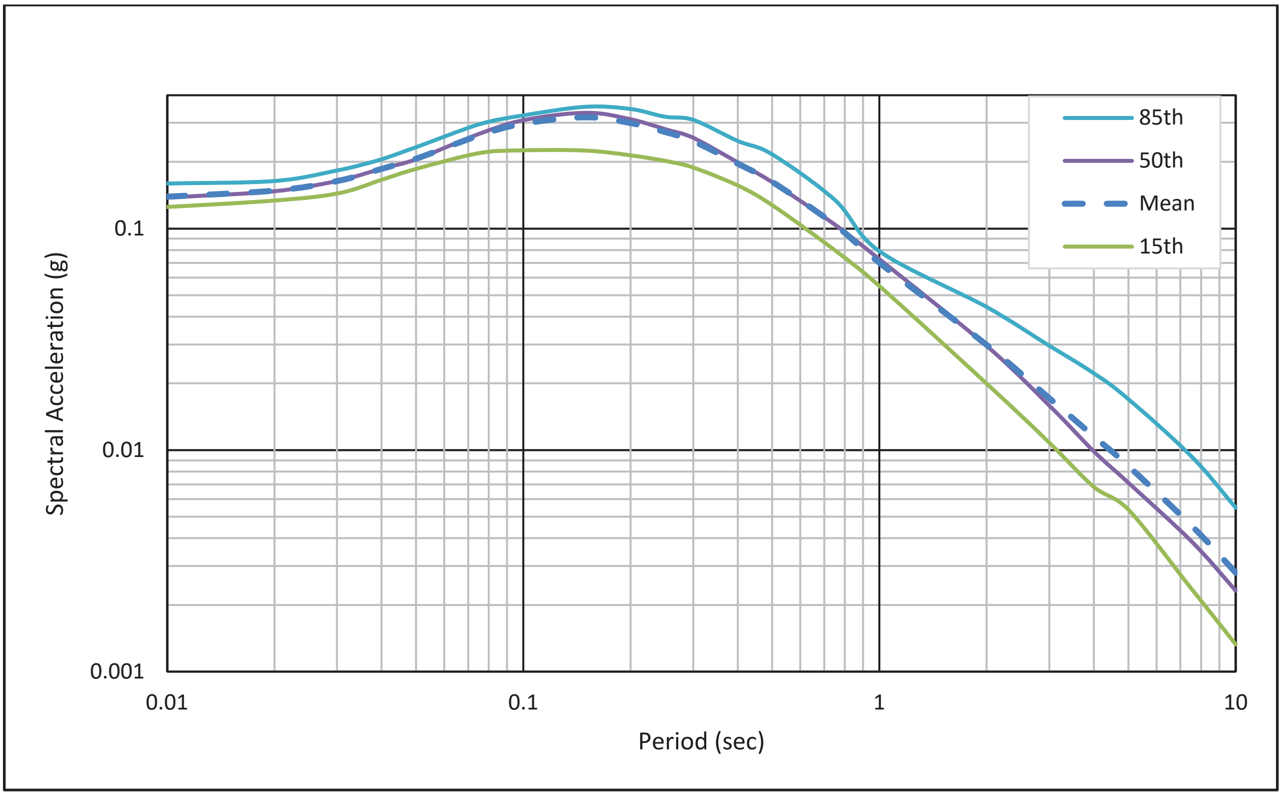


FIGURE 16 FRACTILES OF THE UNIFORM HAZARD SPECTRA FOR THE 5000-YEAR RETURN PERIOD (LOG-LOG)

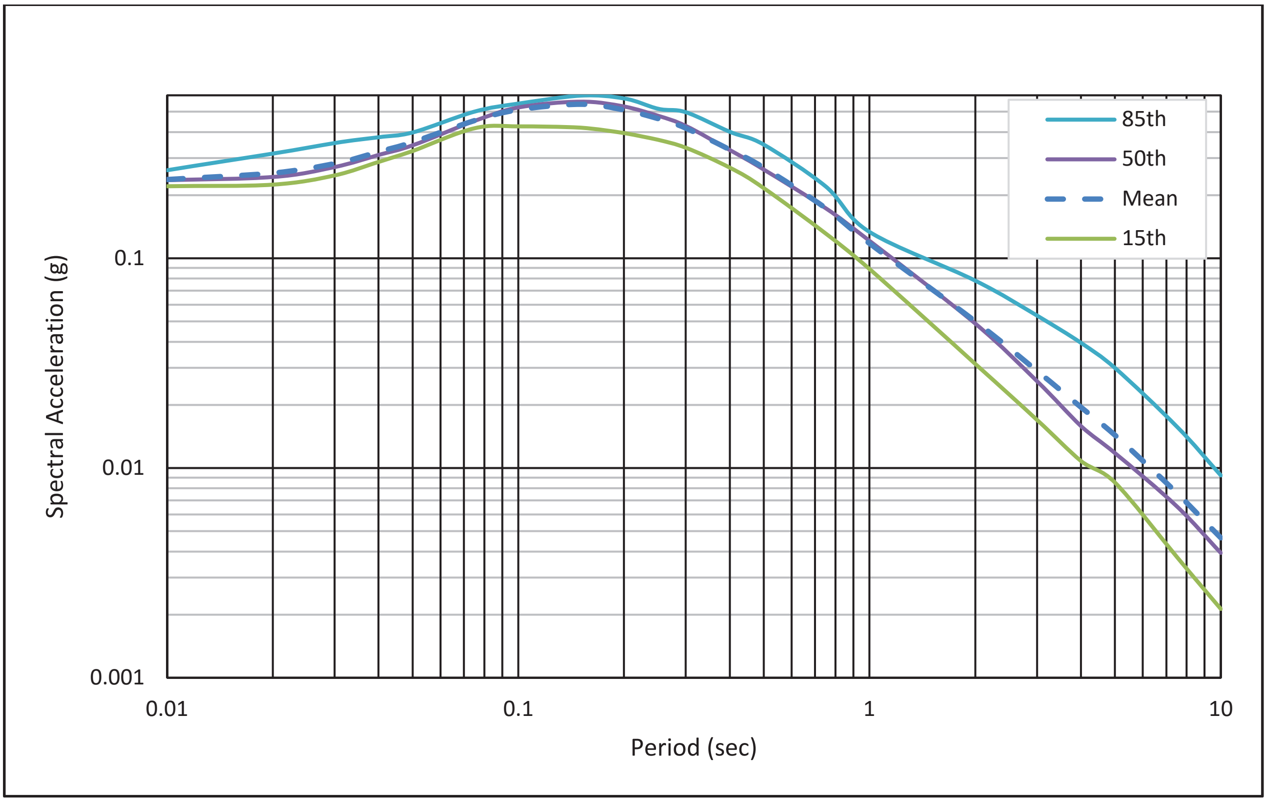
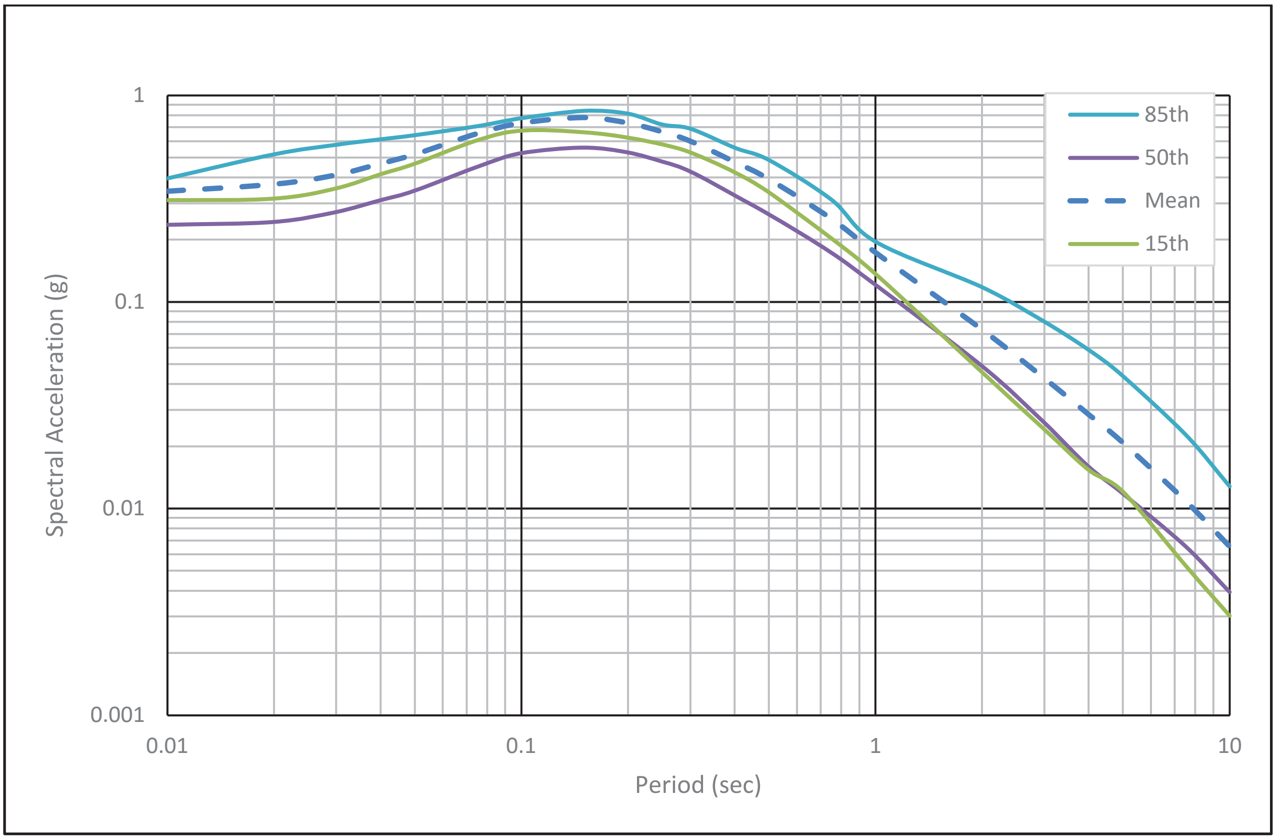


FIGURE 17 FRACTILES OF THE UNIFORM HAZARD SPECTRA FOR THE 10,000-YEAR RETURN PERIOD (LOG-LOG)



9.5 Deaggregation

The deaggregation of the earthquake hazard by magnitude and distance for PGA and for the 5000 year return period are shown in **TABLE 9**, whilst the deaggregation plots are shown in **FIGURE** 18 to **20** for 2000 year, 5000 year and 10,000 year return periods respectively. These results are based on the mean of the ground motion models with a Vs_{30} of 760 m/s for rock and considering only earthquakes of M5.0 and greater.

TABLE 9 COMBINATIONS OF MAGNITUDE, DISTANCE AND EPSILON FOR COSTERFIELD GOLD MINE FOR 2000,5000 and 10000-YR RETURN PERIOD

Period (s)	Mean Distance (km)	Mean Magnitude (M_w)	Mean Epsilon (ε)
PGA (2000)	22.5	6.1	-0.23
PGA (5000)	15.6	6.2	-0.1
PGA (10000)	12	6.3	-0.04

FIGURE 18 DEAGGREGATION OF HAZARD FOR PGA FOR 2000-YEAR RETURN PERIOD

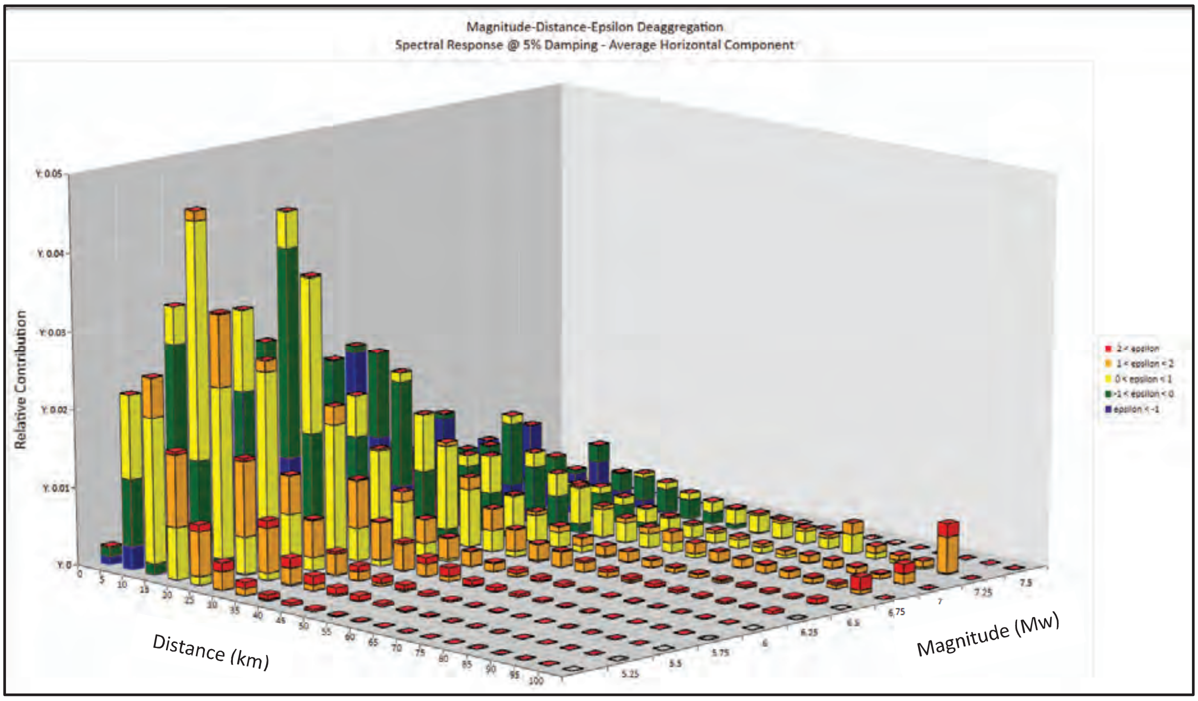


FIGURE 19 DEAGGREGATION OF HAZARD FOR PGA FOR 5000-YEAR RETURN PERIOD

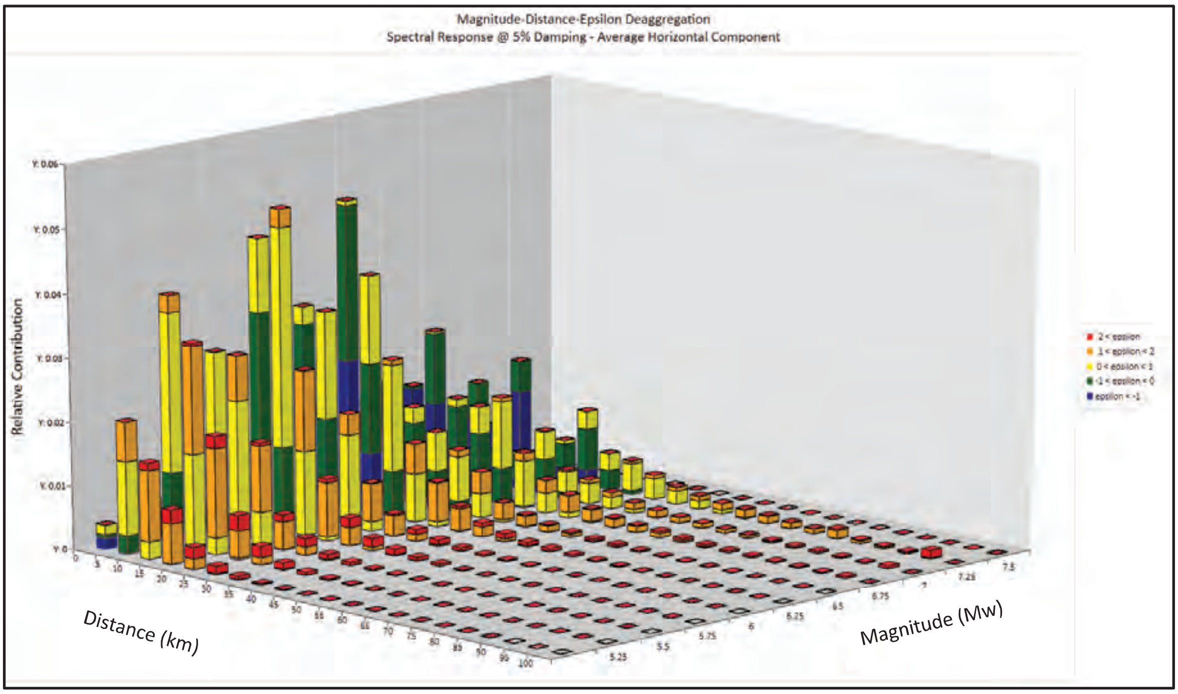
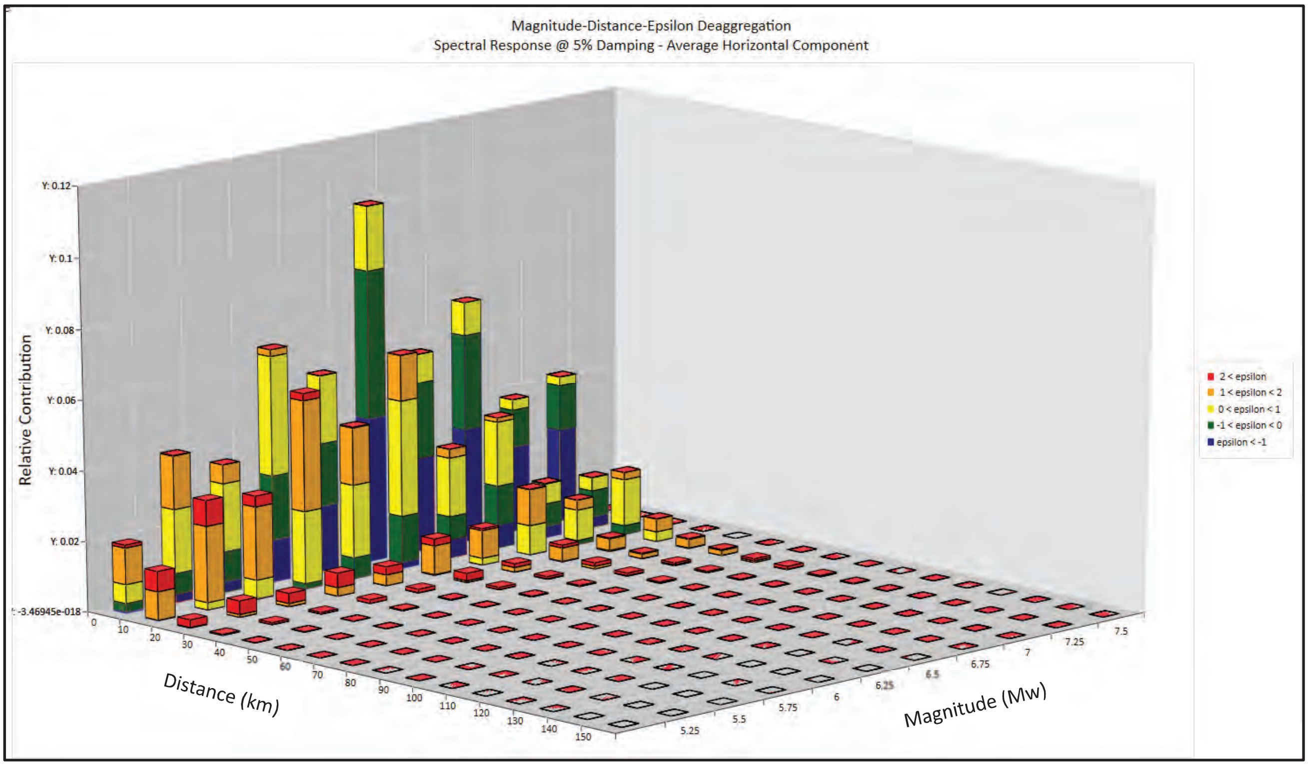


Figure 20 DEAGGREGATION OF HAZARD FOR PGA FOR 10000-YEAR RETURN PERIOD.



9.6 Time History of Accelerations

ANCOLD (2019) **[1]** recommends the use of at least four time-histories of acceleration for advanced dynamic deformation analyses, if required. The time histories for the site specific analysis would be selected ideally from sites with similar seismotectonic conditions, PGA, earthquake magnitude, epicentral distance and rock conditions. The time histories of acceleration for the site were selected from the Pacific Earthquake Engineering Center (PEER) database based on earthquake magnitude, epicentral distance and the average shear-wave velocity in the upper 30 m (Vs_{30}). The sites, and associated recording station data, are presented in **TABLE 10**.

The original time histories of accelerations have been spectrally matched with the target UHS shown in **TABLE 10** for 5,000-year return period. The 5,000 year return period was chosen, as this is considered the design return period based on the Consequence Category of the Brunswick TSF, in accordance with ANCOLD requirements. The plots of original and modified time histories are presented in **Appendix B**. The plots of target UHS and response spectra of the modified time histories are also presented in **Appendix B**.

TABLE 10 RETURN PERIOD = 5,000 YEAR; FREQUENCY = PGA – COSTERFIELD MINE SITE

RSN	Component	5-75% Duration (sec)	5-95% Duration (sec)	Arias Intensity (m/sec)	Earthquake Name	Year	Station Name	Magnitude	Rjb (km)	Rrup (km)	PGA	PGV	PGD	CAV (original)
5653	90	13.78	23.21	0.257	Iwate_ Japan	2008	IWTH21	6.9	84.13	84.13	0.10	3.22	3.22	1.31
	0	11.21	20.3	0.340					84.13	84.13	0.10	4.63	3.16	1.49
14	132	11.52	33.6	0.120	Kern County	1952	Santa Barbara Courthouse	7.36	81.3	82.19	0.13	19.07	5.49	0.70
	42	13.99	29.87	0.101					81.3	82.19	0.09	11.41	3.43	0.61
820	0	8	12.1	0.100	Georgia - USSR	1991	Zem	6.2	51.33	51.38	0.07	4.00	0.57	0.27
	90										0.07	4.85	0.91	0.25
789	207	3.1	8.455	0.038	Loma Prieta	1989	Point Bonita	6.93	83.37	83.45	0.07	12.95	7.33	0.24
	297	2.7	5.27	0.015					83.37	83.45	0.07	11.41	6.45	0.12

RSN is the Record Sequence Number as defined by PEER DB. Rjb is the Joyner-Boore distance measure and is defined as the shortest distance from a site to surface projection of rupture surface.

9.7 Local Site Effects

The design ground accelerations presented in the previous sections were obtained for a site with a rock foundation and shear wave velocity of 760 m/s, which is considered appropriate for the site. For a TSF founded on relatively weak deposits (i.e. with shear wave velocities much lower than 760 m/s) wave propagation analysis should be carried out to estimate the potential amplification of the ground shaking when the waves propagate vertically though the softer soils. The local site effect would potentially increase the predominant period of the earthquake ground motions which may in turn adversely affect TSFs with relatively high natural return periods. The work undertaken in this report does not include a local site effects study.

10 CONCLUSIONS

Costerfield Mine is located in an area of moderate seismicity within Victoria. A site specific PSHA has been undertaken to facilitate the design of a raise for the Brunswick TSF. The study has been undertaken in accordance with the current ANCOLD Seismic Guidelines **[1].**

This report provides earthquake loading parameters for the purpose of structural and geotechnical design.

ATCW have undertaken a series of tasks in order to perform a site-specific PSHA study and have included three seismic source models (with varying weightings) to account for epistemic uncertainty. The first model is the AUS6 area source model, the second model is the DIM-AUS area source model, and the third model is the NSHM13 model. The NSHM13 model is made of two layers, a main source zone layer and a background source zone layer. All the models are composed of a series of zones at shallow depths. The fault sources are included from Geoscience Australia's Neotectonic Faults Database. Five additional faults nearby to Costerfield, not in GA's database, have been included and are in line with current stress regime and regional geology.

A series of outputs have been prepared for Costerfield and include hazard curves for PGA and UHS, as well as deaggregation to provide suitable target scenarios for time history analysis. A V_{S30} of 760 m/s has been adopted for the site assuming a rock foundation. A detailed site response analysis will be required to incorporate the site effects (i.e. from superficial soft soils, tailings or embankment materials).
The site PGA for different return period are calculated and presented in **Table 11**.

Table 11 PGA as a Function of Return Period

Return Periods (years)	PGA (g)
475	0.052
1000	0.088
2000	0.138
5000	0.238
10,000	0.347

The 5,000 year return period was chosen for further analysis, as this is considered the design return period based on the Consequence Category of the Brunswick TSF, in accordance with ANCOLD requirements.

The 5000-year deaggregation for PGA has been calculated to be from earthquakes with a mean magnitude of M6.2 and a mean distance of 15.6 km from the site. A suite of four time histories have been spectrally matched to the 5000-year UHS target spectrum and the data have been provided as plots and output text-files in **Appendix B**. The selected time histories have similar magnitudes, fault mechanisms, site conditions (Site Class B or Vs_{30} 760 m/s), and distance from the site.

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APPENDIX A TABLE A
EARTHQUAKES WITH MAGNITUDE 1.0+ WITHIN 40 KM OF COSTERFIELD SITE

UTC Date & Time	Place/Nearest Location	Magni-tude	Long (°E)	Lat (°S)	Depth (km)	Dist to Site (km)	PGA (mm/s^2)	PGV (mm/s^2)	MMI	Authority
1893-10-09 1243	Seymour	MP 3.0	145.10	-37.00	10	32	142	6.2	3	Und
1898-12-20 0535	Goornong	MP 3.5	144.50	-36.60	5	40	165	8.3	3	Und
1907-10-04 0930	Seymour	MP 4.0	145.10	-37.00	10	32	316	16.9	4	MELOBS
1964-11-10 2135	Nagambie	ML 3.5	144.95	-36.80	10	19	379	16.8	4	Und
1970-10-28 0527	Puckapunyal	ML 3.1	144.87	-36.92	0	10	475	18.0	4	CAN
1971-05-10 064	Harcourt	ML 3.4	144.40	-36.92	0	33	207	9.8	3	CAN
1975-03-07 1131	Lake Eppalock	ML 3.0	144.51	-36.84	10	23	212	8.8	3	BMR
1975-06-02 2311	Lake Eppalock	ML 2.0	144.51	-36.84	10	23	95	3.2	2	BMR
1976-11-01 1603	Metcalfe	ML 1.4	144.52	-37.09	19	31	35	1.1	0	MEL
1977-01-09 1902	Harcourt	ML 2.1	144.34	-36.93	0	38	57	2.2	1	MEL
1977-01-17 0850	Costerfield	ML 1.6	144.94	-36.82	8	18	93	2.8	2	MEL
1977-02-02 0237	Harcourt	ML 2.1	144.36	-36.96	12	37	56	2.1	1	MEL
1977-04-28 1631	Pyalong	ML 2.0	144.82	-37.09	9	23	99	3.3	2	MEL
1977-06-02 1535	Bendigo	MD1.0	144.41	-36.80	11	33	28	0.8	0	MEL
1977-08-17 1516	Pyalong	ML 1.5	144.74	-37.11	10	25	58	1.8	1	MEL
1977-10-08 0523	Heathcote	ML 1.7	144.72	-36.80	10	10	130	3.8	2	MEL
1977-11-08 1825	Colbinabbin	MD2.5	144.78	-36.58	18	35	77	3.1	2	MEL
1977-12-10 0110	Bendigo	MD1.2	144.38	-36.86	22	34	25	0.8	0	MEL
1978-01-24 0938	Redesdale	MD1.5	144.49	-36.96	7	26	59	1.8	1	MEL
1978-04-06 0415	Axedale	MD1.3	144.54	-36.75	0	25	54	1.6	1	MEL
1978-11-08 1553	Tooborac	MD1.1	144.84	-37.05	11	20	53	1.5	1	MEL
1978-12-11 0148	Heathcote	MD1.2	144.67	-36.82	7	11	91	2.4	1	MEL
1978-12-27 0002	Redesdale	MD1.4	144.63	-37.07	18	24	47	1.5	1	MEL
1979-05-19 0819	Tooborac	MD1.1	144.78	-37.00	9	13	76	2.0	1	MEL
1979-08-18 0811	Knowsley	MD1.8	144.61	-36.80	8	17	115	3.5	2	MEL
1979-09-25 2137	Redesdale	MD1.2	144.47	-37.01	2	29	42	1.2	0	MEL
1979-10-14 0739	Harcourt	ML 2.4	144.33	-36.95	4	39	69	2.8	2	MEL
1980-01-17 0014	Harcourt	ML 1.2	144.35	-36.98	11	38	26	0.8	0	MEL
1980-02-25 1209	Mt Camel	MD1.2	144.74	-36.72	2	19	70	1.9	1	MEL
1980-05-30 1434	Mt Camel	MD1.8	144.77	-36.70	2	20	103	3.2	2	MEL
1980-06-21 0621	Tooborac	MD1.0	144.79	-37.07	10	20	50	1.3	1	MEL

1980-09-28 1541	Tooborac	MD1.2	144.72	-37.12	2	26	48	1.4	1	MEL
1981-01-09 1536	Redesdale	MD1.8	144.62	-37.03	0	20	104	3.3	2	MEL
1981-01-09 2312	Harcourt	MD1.7	144.34	-36.96	7	39	39	1.4	1	MEL
1981-01-22 0904	Tooborac	MD1.0	144.80	-37.11	3	24	44	1.2	0	MEL
1981-07-11 1156	Colbinabbin	MD2.4	144.76	-36.52	2	40	67	2.7	2	MEL
1981-08-16 0059	Tooborac	MD1.4	144.73	-37.09	6	23	65	1.9	1	MEL
1982-01-01 2310	Colbinabbin	MD2.0	144.75	-36.55	7	37	54	2.0	1	MEL
1982-03-29 2258	Heathcote	ML 1.6	144.63	-36.95	2	14	122	3.5	2	MEL
1982-06-14 0431	Lancefield	MD2.5	144.65	-37.22	16	39	68	2.9	2	MEL
1983-03-17 1647	Colbinabbin	ML 1.0	144.76	-36.56	15	37	22	0.7	0	MEL
1983-10-25 1658	Redesdale	ML 1.5	144.57	-36.98	6	20	79	2.3	1	MEL
1983-11-22 0127	Colbinabbin	ML 1.4	144.77	-36.64	9	27	50	1.5	1	MEL
1983-12-16 0459	Axedale	ML 1.5	144.52	-36.75	5	27	59	1.8	1	MEL
1985-05-23 1114	Mia Mia	ML 2.7	144.59	-36.94	7	17	239	8.8	3	MEL
1985-06-06 1057	Mt Camel	ML 1.2	144.65	-36.74	0	19	69	1.9	1	MEL
1985-08-10 2034	Colbinabbin	ML 1.8	144.80	-36.62	11	30	60	2.0	1	MEL
1985-08-23 0554	Axedale	ML 1.3	144.53	-36.80	3	23	61	1.8	1	MEL
1985-09-21 1331	Graytown	ML 1.2	144.95	-36.82	5	18	69	1.9	1	MEL
1985-09-23 0727	Axedale	ML 1.3	144.52	-36.74	5	28	47	1.4	1	MEL
1986-01-09 1239	Redesdale	ML 1.3	144.43	-37.04	2	34	36	1.1	0	MEL
1988-01-13 1740	Tooborac	ML 1.0	144.81	-37.01	4	14	72	1.8	1	MEL
1988-07-26 0926	Mt Camel	ML 1.4	144.77	-36.75	4	15	97	2.7	2	MEL
1989-02-25 2018	Tooborac	ML 1.3	144.89	-37.16	10	33	36	1.1	0	MEL
1989-08-08 1147	Tooborac	ML 1.4	144.73	-37.07	0	20	75	2.2	1	MEL
1989-08-14 0311	Toolleen	ML 1.0	144.68	-36.71	16	21	40	1.1	0	MEL
1989-11-15 0836	Costerfield	ML 2.1	144.92	-36.82	6	16	157	5.1	2	MEL
1989-11-25 1435	Costerfield	ML 1.5	144.92	-36.83	4	15	104	3.0	2	MEL
1990-03-07 0659	Mt Camel	ML 2.1	144.73	-36.70	11	21	114	3.9	2	MEL
1990-06-19 2126	Redesdale	ML 1.2	144.60	-37.12	8	30	38	1.2	0	MEL
1990-08-12 1151	Heathcote	ML 1.0	144.62	-36.92	8	13	69	1.8	1	MEL
1990-11-13 1251	Harcourt	ML 1.7	144.32	-36.96	7	40	38	1.3	1	MEL
1990-11-15 0101	Harcourt	ML 1.1	144.33	-36.93	4	39	25	0.8	0	MEL
1990-11-30 1350	Harcourt	ML 1.2	144.32	-36.95	8	40	25	0.8	0	MEL
1991-02-27 2000	Redesdale	ML 1.1	144.55	-36.98	8	22	51	1.4	1	MEL
1991-06-17 1640	Colbinabbin	ML 1.8	144.75	-36.58	4	34	53	1.8	1	MEL

1991-06-17 1643	Colbinabbin	ML 1.2	144.74	-36.58	4	34	34	1.0	0	MEL
1991-06-20 2016	Colbinabbin	ML 1.2	144.75	-36.60	11	32	34	1.0	0	MEL
1991-07-18 0857	Lake Eppalock	ML 1.2	144.51	-36.94	9	23	51	1.5	1	MEL
1991-10-10 1416	Heathcote	ML 1.7	144.70	-36.96	4	10	150	4.3	2	MEL
1991-10-11 1443	Heathcote	ML 1.8	144.70	-36.96	6	10	159	4.7	2	MEL
1991-11-16 0725	Redesdale	ML 1.0	144.54	-36.96	4	21	51	1.4	1	MEL
1992-03-25 0611	Harcourt	ML 1.1	144.33	-36.94	4	40	24	0.8	0	MEL
1992-06-15 0315	Tooborac	ML 1.2	144.85	-37.09	5	24	52	1.5	1	MEL
1992-09-03 0627	Axedale	ML 1.0	144.49	-36.85	10	25	40	1.1	0	MEL
1992-11-25 0953	Colbinabbin	ML 1.1	144.77	-36.67	2	24	50	1.4	1	MEL
1993-04-02 0536	Mt Camel	ML 1.3	144.70	-36.74	4	17	82	2.3	1	MEL
1995-02-22 0254	Colbinabbin	ML 1.7	144.70	-36.61	10	32	51	1.7	1	MEL
1995-11-18 0932	Tooborac	ML 3.7	144.76	-37.11	13	25	317	15.4	4	MEL
1995-12-06 0013	Lake Eppalock	ML 2.0	144.49	-36.86	0	24	100	3.4	2	MEL
1996-06-16 0815	Elmore	ML 1.9	144.58	-36.58	3	38	49	1.8	1	MEL
1996-06-26 1740	Riddells Creek	ML 1.0	144.66	-37.19	10	35	26	0.8	0	MEL
1997-01-16 1559	Goornong	ML 1.7	144.53	-36.64	4	35	48	1.6	1	MEL
1997-02-28 0021	Rushworth	ML 1.2	144.95	-36.57	4	39	27	0.9	0	MEL
1997-08-28 0838	Rushworth	ML 2.2	144.98	-36.58	4	40	59	2.3	1	MEL
1998-12-25 2153	Whroo	ML 1.9	145.02	-36.65	10	35	52	1.9	1	MEL
1999-04-14 1617	Goornong	ML 1.5	144.53	-36.70	10	29	49	1.6	1	MEL
1999-04-17 1613	Goornong	ML 2.2	144.47	-36.67	1	35	71	2.7	2	MEL
2000-02-05 2235	S of Mt Ida	ML 1.6	144.66	-36.99	10	14	101	3.0	2	MEL
2000-03-17 0541	NW of Tallarook	ML 1.4	145.09	-37.09	9	37	34	1.1	0	MEL
2000-03-28 0608	NW of Tallarook	ML 1.4	145.10	-37.10	10	38	32	1.1	0	MEL
2000-05-07 0952	W of Whroo	ML 1.5	144.92	-36.68	4	27	58	1.8	1	MEL
2000-06-22 1813	W of Graytown	ML 3.1	144.86	-36.82	6	12	415	16.0	4	MEL
2000-06-22 1942	W of Graytown	ML 1.6	144.88	-36.81	6	13	118	3.4	2	MEL
2000-07-11 0205	Redesdale	ML 1.5	144.46	-36.97	5	29	52	1.7	1	MEL
2001-02-11 0700	S of Redesdale	ML 1.6	144.53	-37.08	10	30	51	1.7	1	MEL
2001-03-20 0758	S of Mt Camel	ML 1.9	144.71	-36.77	4	14	152	4.6	2	MEL
2001-03-29 1421	SW of Tooborac	ML 1.4	144.66	-37.15	9	30	44	1.4	1	MEL
2001-04-05 1050	SW of Tooborac	ML 1.8	144.67	-37.15	9	30	61	2.1	1	MEL
2001-06-03 1621	Redesdale	ML 2.1	144.52	-36.98	11	24	97	3.4	2	AUST
2001-09-07 0926	Redesdale	ML 1.5	144.52	-37.02	0	26	61	1.9	1	MEL

2001-09-08 1601	Graytown	ML 1.3	144.88	-36.76	8	17	74	2.1	1	MEL
2001-09-18 2314	N of Redesdale	ML 1.3	144.53	-37.01	0	25	55	1.6	1	MEL
2002-03-27 0501	Puckapunyal	ML 1.9	145.05	-37.03	0	30	70	2.4	1	MEL
2002-05-05 0726	NW of Redesdale	ML 1.7	144.51	-37.01	6	26	68	2.2	1	MEL
2002-07-29 0013	Bendigo	ML 1.7	144.48	-36.72	10	32	51	1.7	1	MEL
2002-12-18 2125	NW of Redesdale	ML 1.5	144.48	-36.96	10	27	55	1.7	1	MEL
2003-01-28 0442	Nagambie	ML 1.1	144.92	-36.85	4	15	76	2.0	1	MEL
2003-04-03 0614	N of Seymour	ML 1.9	145.12	-36.96	0	33	62	2.2	1	MEL
2003-11-07 2149	Elmore	ML 1.7	144.60	-36.56	10	40	37	1.3	0	MEL
2004-01-18 1542	Nagambie	ML 1.1	145.06	-36.80	13	28	35	1.0	0	MEL
2004-01-20 1804	Rushworth	ML 1.7	144.87	-36.61	8	32	51	1.7	1	MEL
2005-07-05 1238	N of Mt Camel	ML 1.5	144.72	-36.72	4	19	87	2.5	1	MEL
2007-04-26 1116	Lake Eppalock	ML 1.5	144.57	-36.87	6	17	91	2.6	2	GG
2008-10-09 0141	Axedale	ML 2.0	144.47	-36.80	10	28	78	2.7	2	MEL
2010-03-20 0011	Mt Camel	ML 2.3	144.74	-36.72	3	18	169	5.8	3	MEL
2010-04-19 1908	Mt Camel	ML 1.0	144.72	-36.70	10	21	47	1.3	0	MEL
2010-05-17 2104	Mt Camel	ML 1.2	144.65	-36.74	10	19	60	1.7	1	MEL
2010-05-26 1009	NE of Mt Camel	ML 3.2	144.74	-36.75	10	16	344	14.1	4	MEL
2010-05-26 1029	Axedale	ML 1.8	144.75	-36.76	10	15	118	3.6	2	MEL
2010-06-23 1023	Fosterville	ML 1.7	144.53	-36.68	10	31	53	1.8	1	MEL
2010-09-18 0713	Rushworth	ML 1.3	145.07	-36.63	4	39	29	0.9	0	MEL
2010-10-06 0825	Rushworth	ML 1.7	144.96	-36.62	10	35	46	1.6	1	MEL
2012-08-18 0016	SSW of Mt Camel	ML 1.6	144.70	-36.80	10	11	114	3.3	2	MEL
2012-11-22 1938	NNE of Axedale	ML 1.2	144.54	-36.72	10	28	41	1.2	0	MEL
2013-04-07 2035	NNE of Axedale	ML 1.4	144.56	-36.71	10	27	50	1.5	1	MEL
2013-04-18 1342	SSW of Redesdale	ML 1.3	144.52	-37.04	1	28	49	1.5	1	MEL
2013-06-09 0352	W of Mt Camel	ML 1.8	144.72	-36.76	0	15	138	4.1	2	MEL
2013-08-15 1755	NE of Sutton Grange	ML 1.0	144.40	-36.96	8	34	28	0.8	0	MEL
2014-01-16 0106	SW of Rushworth	ML 1.2	144.86	-36.67	4	25	50	1.4	1	MEL
2014-07-30 0633	Lake Eppalock	ML 1.1	144.59	-36.87	9	16	66	1.8	1	MEL
2014-08-31 1042	NNE of Goornong	ML 1.2	144.52	-36.59	13	40	24	0.8	0	MEL
2015-05-11 1518	SW of Eppalock Dam	ML 1.0	144.50	-36.88	10	24	42	1.2	0	SRC
2015-08-09 0319	SSE of Redesdale	ML 1.2	144.62	-37.14	10	31	36	1.1	0	SRC
2015-08-29 1342	SSE of Redesdale	ML 1.8	144.60	-37.11	1	28	70	2.3	1	SRC
2015-12-16 2129	SSW of Colbinabbin	ML 2.3	144.76	-36.65	5	27	110	4.0	2	SRC

2016-03-19 0644	ESE of Fosterville	ML 1.1	144.55	-36.71	13	28	36	1.1	0	SRC
2016-10-18 1854	ENE of Costerfield	ML 2.5	144.87	-36.86	0	10	300	10.0	3	AUST
2016-10-19 0232	N of Graytown	ML 2.2	144.96	-36.78	7	22	127	4.4	2	AUST
2017-06-19 1138	ENE of Costerfield	ML 1.4	144.84	-36.86	9	7	115	3.1	2	SRC
2017-08-08 2303	N of Lancefield	ML 1.7	144.73	-37.10	5	24	79	2.5	1	SRC
2017-09-01 1644	E of Fosterville Mine	ML 1.0	144.51	-36.72	3	29	35	1.0	0	SRC
2018-01-11 0503	ENE of Heathcote	ML 1.0	144.89	-36.85	6	12	77	1.9	1	SRC
2018-04-24 1409	W Fosterville Mine	ML 1.1	144.47	-36.73	10	31	33	1.0	0	SRC
2018-08-31 0322	S of Rushworth	ML 1.5	145.02	-36.63	6	37	37	1.2	0	SRC

(Source: Gary Gibson, GGcat-2020-04-16 version). Notes: Und = Underwood.

APPENDIX A TABLE B
EARTHQUAKES WITH INTENSITIES MMI 2+ WITHIN 40 KM OF COSTERFIELD SITE

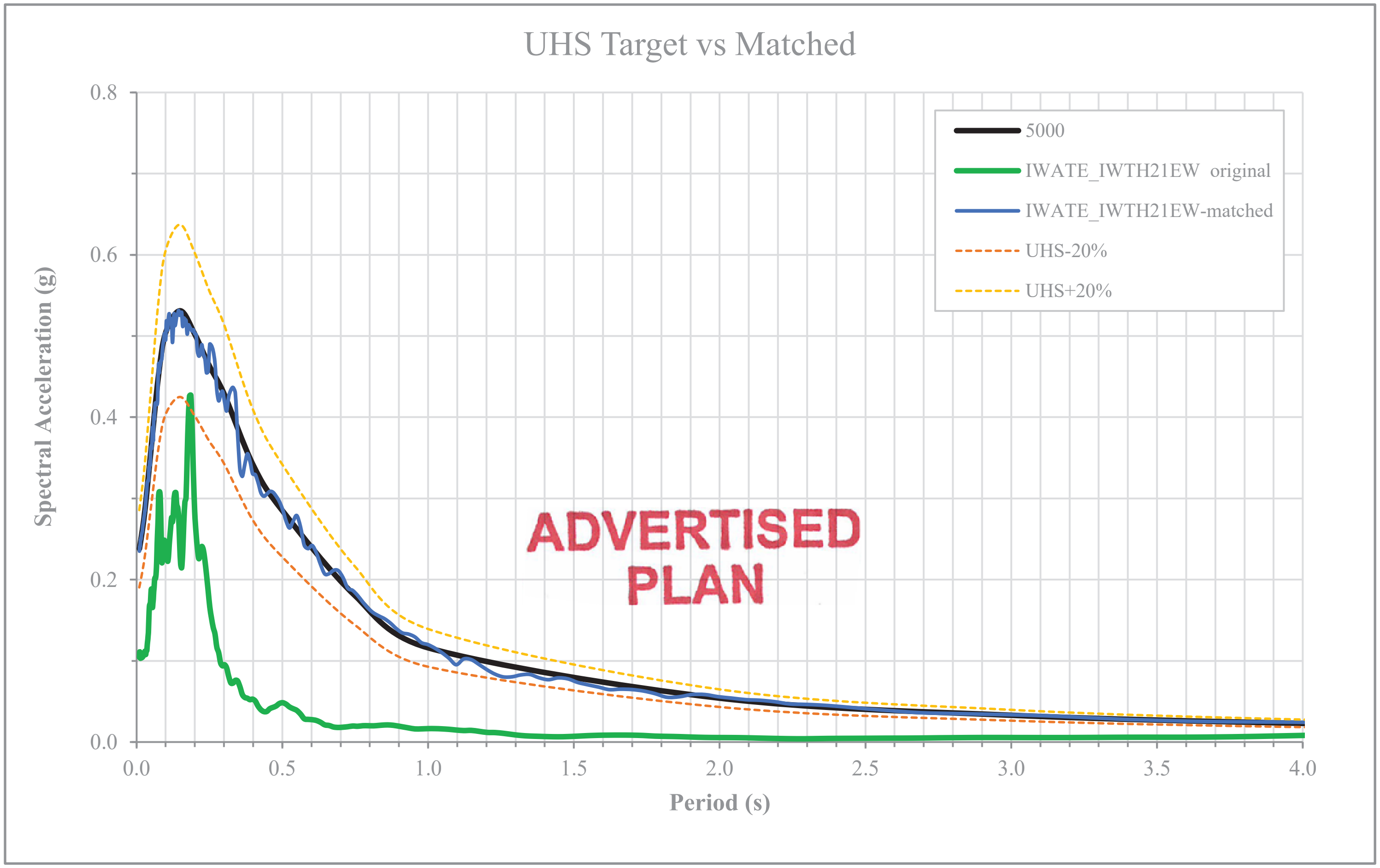
UTC Date & Time	Place	Magni-tude	Long (˚E)	Lat (˚S)	Depth (km)	Dist to Site (km)	PGA (mm/s^2)	PGV (mm/s^2)	MMI	Authority
1970-10-28 0527	Puckapunyal	ML 3.1	144.87	-36.92	0	10	475	18.0	4	CAN
1907-10-04 0930	Seymour	MP 4.0	145.10	-37.00	10	32	316	16.9	4	MELOBS
1964-11-10 2135	Nagambie	ML 3.5	144.95	-36.80	10	19	379	16.8	4	Und
2000-06-22 1813	W of Graytown	ML 3.1	144.86	-36.81	6	12	415	16.0	4	MEL
1995-11-18 0932	Tooborac	ML 3.7	144.76	-37.11	14	25	317	15.4	4	MEL
2010-05-26 1009	NE of Mt Camel	ML 3.2	144.74	-36.74	10	16	344	14.1	4	MEL
2016-10-18 1854	ENE of Costerfield	ML 2.5	144.86	-36.85	0	10	300	10.0	3	AUST
1971-05-10 0649	Harcourt	ML 3.4	144.40	-36.92	0	33	207	9.8	3	CAN
1975-03-07 1131	Lake Eppalock	ML 3.0	144.51	-36.84	10	23	212	8.8	3	BMR
1985-05-23 1114	Mia Mia	ML 2.7	144.58	-36.93	7	17	239	8.8	3	MEL
1956-01-07 0000	Castlemaine	MP 4.0	144.20	-37.10	10	56	137	8.3	3	MELOBS
1898-12-20 0535	Goornong	MP 3.5	144.50	-36.60	5	40	165	8.3	3	Und
1932-10-26 0308	Serpentine	MP 4.5	144.00	-36.50	10	81	104	7.8	3	MELOBS
1969-07-11 0621	SW of Bendigo	ML 4.0	144.10	-36.83	0	60	124	7.7	3	CAN
1893-10-09 1243	Seymour	MP 3.0	145.10	-37.00	10	32	142	6.2	3	Und
1961-04-10 1410	S of Maldon	ML 4.0	144.05	-37.14	0	69	94	6.0	3	CAN
1963-04-02 1909	Elphinstone	ML 3.3	144.35	-37.10	0	44	121	6.0	3	CAN
1978-11-25 0829	Rushworth	ML 3.5	144.98	-36.49	17	48	111	5.9	3	MEL
2010-03-20 0011	Mt Camel	ML 2.3	144.73	-36.72	3	18	169	5.8	3	MEL
1902-03-08 1030	Harcourt	MP 3.5	144.20	-37.00	10	52	103	5.6	3	GG
1956-01-09 0000	Castlemaine	MP 3.5	144.20	-37.00	10	52	103	5.6	3	MELOBS
2012-06-19 1053	ENE of Thorpdale	ML 5.6	146.29	-38.25	18	203	42	5.1	3	GG
2002-01-22 0918	S of Rochester	ML 3.4	144.70	-36.44	13	50	100	5.3	3	MEL
1960-06-01 0518	Nagambie	ML 3.5	145.35	-36.76	12	54	95	5.2	3	CAN
1977-12-02 1332	W of Balliang	ML 4.7	144.19	-37.85	14	119	58	5.0	3	MEL
1968-10-16 1713	Shelbourne	ML 3.8	144.00	-36.82	0	69	82	5.0	3	CAN
1989-11-15 0836	Costerfield	ML 2.1	144.92	-36.82	6	16	157	5.1	2	MEL
1855-09-16 1712	Bass Strait	MP 5.5	144.80	-38.70	10	201	40	4.7	2	GG
1956-08-14 1720	Geelong	MP 4.5	144.20	-37.80	10	113	55	4.5	2	GG
1991-05-03 1728	Bradford Hills	ML 3.5	144.08	-36.89	1	60	81	4.5	2	MEL
1921-05-30 1451	SSE of Hay, NSW	ML 5.5	145.00	-35.00	10	210	36	4.4	2	BurkeG
1991-10-11 1443	Heathcote	ML 1.8	144.70	-36.96	5	10	159	4.7	2	MEL
2001-03-20 0758	S of Mt Camel	ML 1.9	144.71	-36.77	4	14	152	4.6	2	MEL
1982-11-21 1134	Wonnangatta	ML 5.4	146.97	-37.21	14	200	37	4.3	2	MEL
1907-05-27 1547	Maldon	MP 3.5	144.10	-37.00	10	60	79	4.4	2	Und
1971-02-08 1449	Echuca	ML 4.3	145.02	-36.01	22	100	57	4.4	2	CAN
1966-05-03 1907	Mt Hotham	ML 5.5	147.16	-37.04	15	215	35	4.2	2	Denham
2016-10-19 0232	N of Graytown	ML 2.2	144.96	-36.77	7	22	127	4.4	2	AUST
1913-03-02 1745	Benalla	MP 4.5	146.00	-36.50	15	119	50	4.1	2	GG
1922-04-10 1046	King Island, Tas	MP 5.7	144.85	-39.14	0	250	30	4.0	2	Leiba
1991-10-10 1416	Heathcote	ML 1.7	144.70	-36.96	4	10	150	4.3	2	MEL
1903-07-10 0356	Maryborough	MP 4.0	143.80	-37.00	20	87	59	4.1	2	GG
1944-11-02 1405	Marysville	ML 4.5	145.90	-37.50	10	122	48	4.0	2	GG
1885-05-12 2337	E Flinders Is, Tasman Sea	MP 6.8	148.90	-39.90	10	492	19	3.8	2	Leiba
2001-05-02 0135	E of Malmsbury	ML 3.0	144.44	-37.17	18	43	86	4.1	2	MEL
2013-06-09 0352	W of Mt Camel	ML 1.8	144.71	-36.76	0	15	138	4.1	2	MEL
1885-07-02 1603	Tasman Sea	MP 5.7	146.00	-39.00	-	258	28	3.8	2	Leiba
2015-12-16 2129	SSW of Colbinabbin	ML 2.3	144.76	-36.64	5	27	110	4.0	2	SRC
1902-12-22 1245	Port Phillip Bay	MP 4.5	144.80	-38.00	20	124	46	3.8	2	BurkeG
1965-09-14 1253	Off Lorne, Bass Strait	ML 5.3	144.30	-38.70	10	205	33	3.7	2	Und

1964-06-28 1338	Tatura	ML 3.5	145.24	-36.41	5	68	65	3.8	2	CAN
1990-03-07 0659	Mt Camel	ML 2.1	144.72	-36.70	11	21	114	3.9	2	MEL
1922-02-28 1500	Bass Strait	MP 5.5	145.00	-39.00	10	235	29	3.6	2	MELOBS
1903-09-04 1045	Dunolly	MP 4.0	143.70	-36.90	0	95	52	3.7	2	MELOBS
1971-07-06 2154	Westernport Bay	ML 5.0	145.04	-38.45	17	175	35	3.6	2	MEL
1977-10-08 0523	Heathcote	ML 1.7	144.72	-36.80	10	10	130	3.8	2	MEL
1893-07-22 1535	Newstead	MP 3.5	144.00	-37.00	10	69	62	3.6	2	Und
1892-01-26 1648	E Flinders Is, Tasman Sea	MP 6.9	149.50	-40.40	10	567	15	3.3	2	Leiba
2010-05-26 1029	Axedale	ML 1.8	144.74	-36.75	10	15	118	3.6	2	MEL
1957-08-16 0603	Nagambie	MP 3.0	145.30	-36.75	10	50	73	3.5	2	GG
1957-08-16 1916	Nagambie	MP 3.0	145.30	-36.75	10	50	73	3.5	2	Und
1957-08-18 2019	Nagambie	MP 3.0	145.30	-36.75	10	50	73	3.5	2	Und
1957-08-21 1210	Nagambie	MP 3.0	145.30	-36.75	10	50	73	3.5	2	Und
1957-08-21 1219	Nagambie	MP 3.0	145.30	-36.75	10	50	73	3.5	2	Und
1897-05-10 0526	Kingston-Beachport, SA	MP 6.5	139.75	-37.30	14	448	18	3.3	2	KMcC
1903-07-14 1028	Warrnambool	MP 5.6	142.53	-38.43	10	261	26	3.3	2	KMcC
1996-09-25 0749	Thomson Reservoir	ML 5.0	146.42	-37.86	11	182	32	3.4	2	MEL
2008-03-01 0024	SW of Echuca	ML 3.7	144.66	-36.15	10	82	54	3.4	2	AUST
1979-08-18 0811	Knowsley	MD1.8	144.61	-36.80	7	17	115	3.5	2	MEL
1969-07-11 0801	SW of Bendigo	ML 3.5	143.95	-36.91	0	73	58	3.4	2	CAN
1969-06-20 1115	Boolarra	ML 5.3	146.30	-38.47	19	222	28	3.2	2	BMR
1982-03-29 2258	Heathcote	ML 1.6	144.62	-36.94	2	14	122	3.5	2	MEL
1968-10-08 1023	Tatong	ML 4.3	146.12	-36.78	6	122	41	3.3	2	CAN
1906-06-17 1530	Daylesford	MP 3.0	144.22	-37.08	0	53	69	3.4	2	MELOBS
1898-09-06 0415	Alexandra	MP 4.0	145.70	-37.40	10	101	46	3.3	2	Und
1847-04-28 0630	Melbourne	MP 4.0	144.80	-37.80	10	101	46	3.3	2	Und
2001-06-03 1621	Redesdale	ML 2.1	144.51	-36.97	11	24	97	3.4	2	AUST
2000-06-22 1942	W of Graytown	ML 1.6	144.88	-36.81	5	13	118	3.4	2	MEL
1995-12-06 0013	Lake Eppalock	ML 2.0	144.49	-36.86	0	24	100	3.4	2	MEL
1977-04-28 1631	Pyalong	ML 2.0	144.81	-37.08	9	23	99	3.3	2	MEL
1981-06-16 2133	Off Lorne, Bass Strait	ML 5.3	144.24	-38.89	17	228	26	3.1	2	MEL
1931-03-13 2111	NE of King Island, Bass Str	MP 5.7	144.50	-39.50	10	291	22	3.1	2	Und
2012-08-18 0016	SSW of Mt Camel	ML 1.6	144.69	-36.80	10	11	114	3.3	2	MEL
1981-01-09 1536	Redesdale	MD1.8	144.62	-37.02	0	20	104	3.3	2	MEL
2016-11-14 1616	ESE of Broadford	ML 2.8	145.10	-37.21	10	47	69	3.2	2	AUST
1975-06-02 2311	Lake Eppalock	ML 2.0	144.51	-36.84	10	23	95	3.2	2	BMR
1980-05-30 1434	Mt Camel	MD1.8	144.77	-36.70	2	20	103	3.2	2	MEL
1981-07-01 1218	Rushworth	ML 2.8	144.92	-36.47	0	48	68	3.1	2	MEL
1977-11-08 1825	Colbinabbin	MD2.5	144.78	-36.57	18	35	77	3.1	2	MEL
2020-03-23 0032	S of Broadford	ML 2.8	145.05	-37.25	10	48	66	3.1	2	AUST
1891-06-07 0424	Port Phillip Bay	MP 4.5	144.90	-38.20	10	146	33	2.9	2	Und
2017-06-19 1138	ENE of Costerfield	ML 1.4	144.83	-36.86	9	7	115	3.1	2	SRC
1869-08-29 1850	Eastern Highlands	MP 5.0	147.00	-37.00	10	200	27	2.9	2	Und
1904-04-09 2205	Bright	ML 5.0	147.00	-36.80	10	200	27	2.9	2	MELOBS
2016-05-01 1700	SSW of Ravenswood	ML 2.8	144.20	-36.91	6	50	65	3.0	2	SRC
1960-12-24 1642	Cape Otway	ML 5.3	143.59	-38.88	0	244	23	2.8	2	ADE
2000-02-05 2235	S of Mt Ida	ML 1.6	144.65	-36.98	10	14	101	3.0	2	MEL
1991-06-08 1955	Bradford Hills	ML 3.0	144.10	-36.88	0	58	58	2.9	2	MEL
1932-10-27	Serpentine	MP 3.5	144.00	-36.50	10	81	47	2.9	2	MELOBS
1989-11-25 1435	Costerfield	ML 1.5	144.91	-36.83	4	15	104	3.0	2	MEL
1932-09-02 1822	Mornington	ML 4.5	145.00	-38.25	5	153	31	2.7	2	Holmes
1982-06-14 0431	Lancefield	MD2.5	144.64	-37.22	16	39	68	2.9	2	MEL
1965-09-14 1234	Off Lorne, Bass Strait	ML 5.0	144.20	-38.70	10	207	25	2.7	2	Und
1966-09-05 1757	Echuca	ML 3.4	144.52	-36.23	17	76	47	2.8	2	CAN

1912-08-11 0715	Bealiba	MP 4.0	143.5	-36.8	10	113	37	2.7	2	MELOBS
1979-10-14 0739	Harcourt	ML 2.4	144.32	-36.94	4	39	69	2.8	2	MEL
1899-12-01 1255	Western Riverina, NSW	MP 5.0	145.00	-35.00	10	210	24	2.6	2	Und
1977-01-17 0850	Costerfield	ML 1.6	144.94	-36.82	8	18	93	2.8	2	MEL
1981-07-11 1156	Colbinabbin	MD2.4	144.76	-36.52	2	40	67	2.7	2	MEL
2008-10-09 0141	Axedale	ML 2.0	144.47	-36.80	10	28	78	2.7	2	MEL
1999-04-17 1613	Goornong	ML 2.2	144.47	-36.67	1	35	71	2.7	2	MEL
1988-07-26 0926	Mt Camel	ML 1.4	144.77	-36.75	4	15	97	2.7	2	MEL
1903-04-06 2352	Warrnambool	MP 5.3	142.53	-38.43	10	261	20	2.5	2	KMcC
1905-08-21 1600	SW of Nhill, West Vict	MP 5.5	141.50	-36.50	15	295	19	2.5	2	GG
2007-04-26 1116	Lake Eppalock	ML 1.5	144.57	-36.86	6	17	91	2.6	2	GG

(Source: Gary Gibson, GGcat-2020-04-16 version) Notes: Und = Underwood.

Iwate, 13/6/2008, IWTH21, 90 EQ Records-Matched



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Costerfield Dam

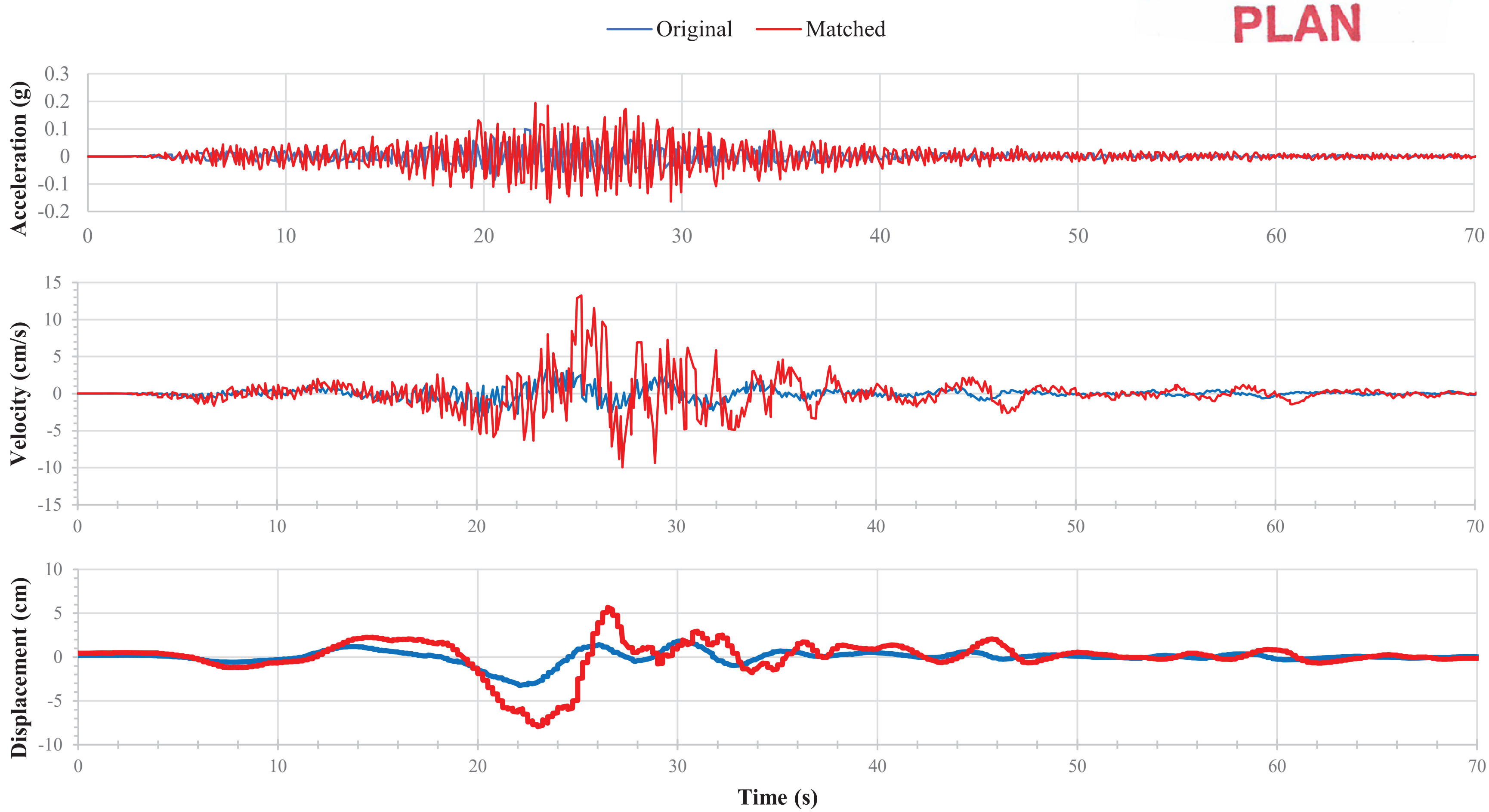
PSHA of Costerfield Dam

5,000 year UHS - Target vs Matched Spectra

Date: 16/10/2020 Job No. 109014.08

APPENDIX B-1

Iwate, 13/6/2008, IWTH21, 90 EQ Records-Scaled



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Costerfield Dam

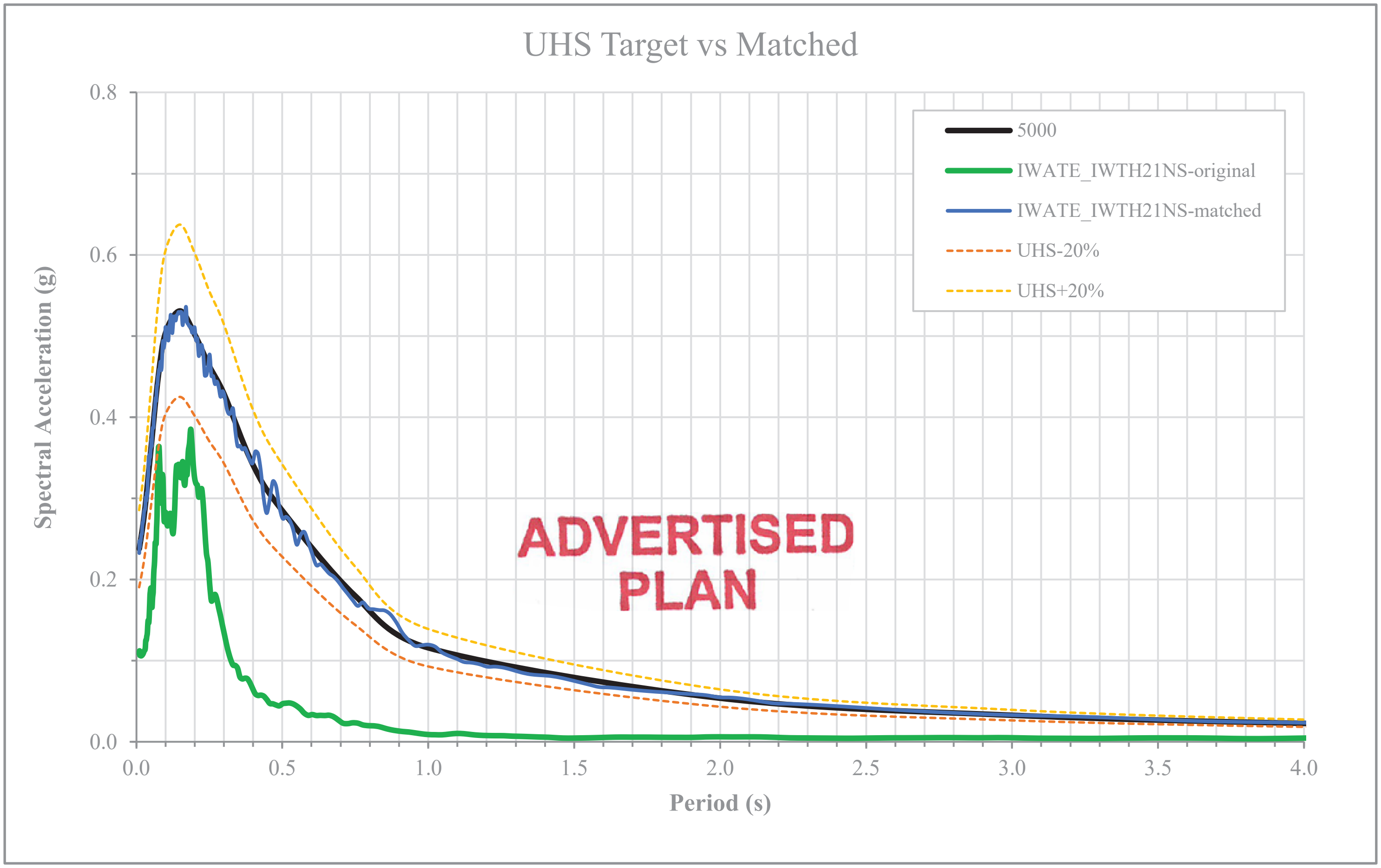
PSHA of Costerfield Dam

Time history of accelerations, velocity and displacement

Date: 16/10/2020 Job No. 109014.08

APPENDIX B-2

Iwate, 13/6/2008, IWTH21, 00 EQ Records-Matched



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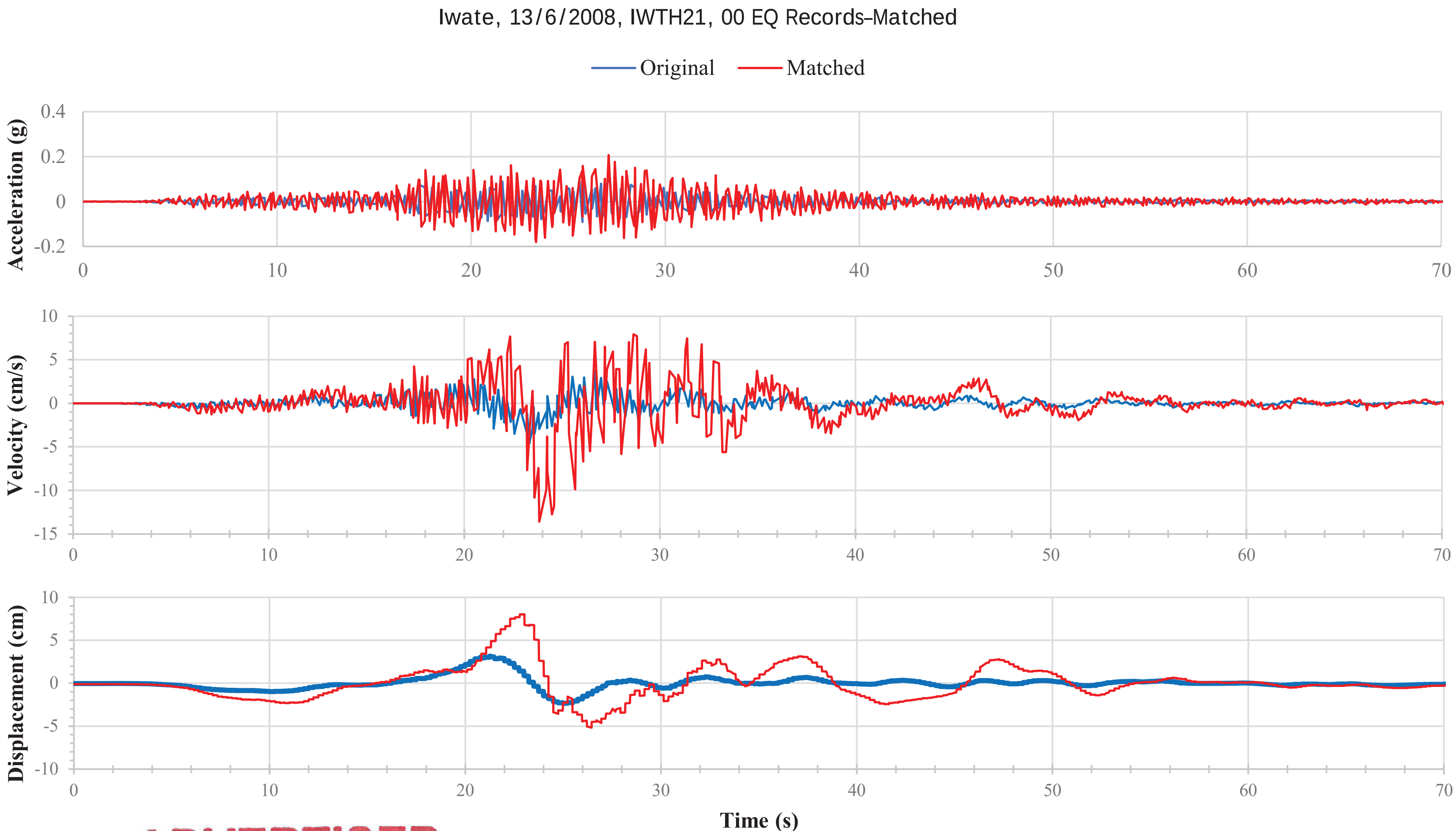
Costerfield Dam

PSHA of Costerfield Dam

5,000 year UHS - Target vs Matched Spectra

Date: 16/10/2020 Job No. 109014.08

APPENDIX B-3



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Costerfield Dam

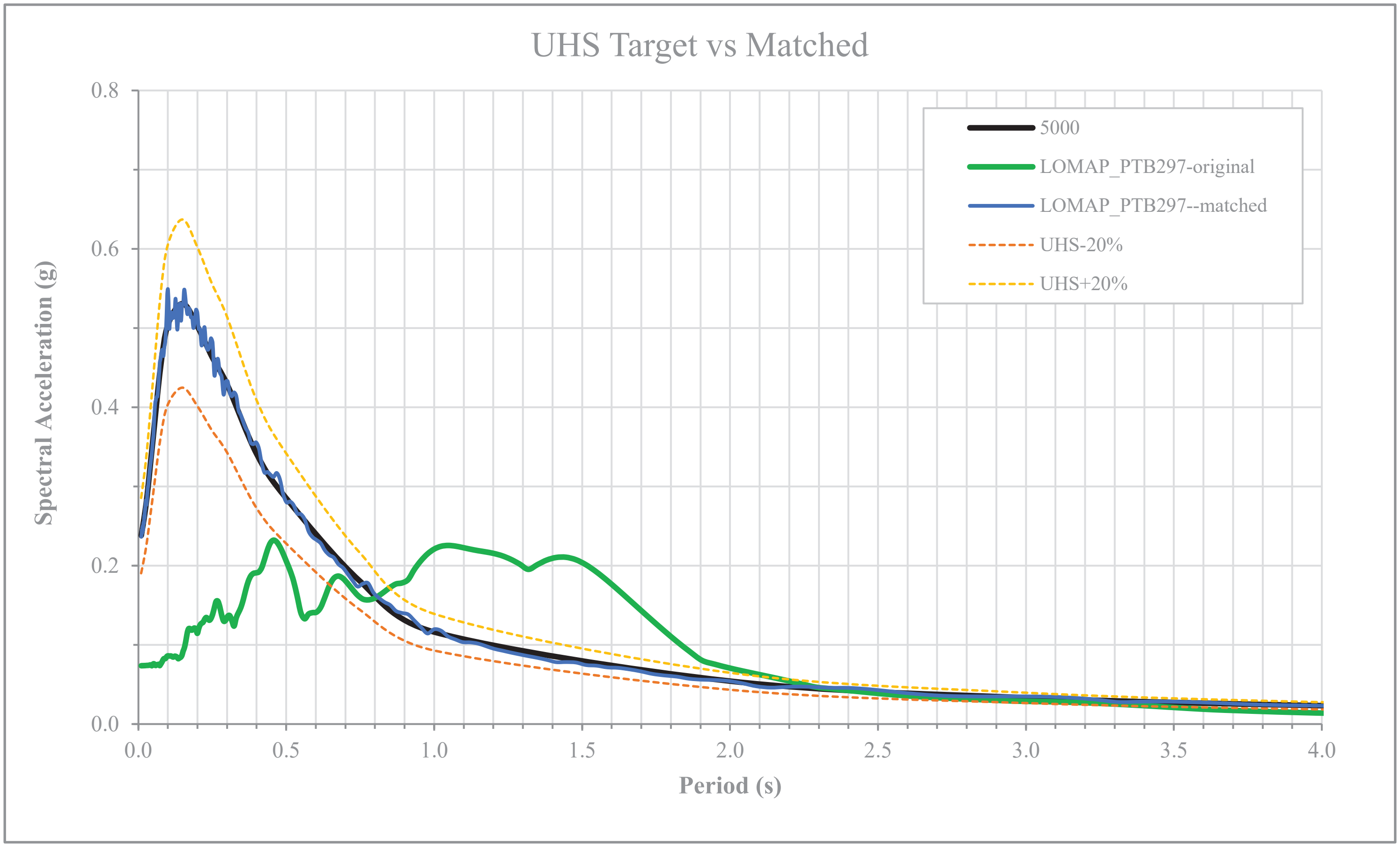
PSHA of Costerfield Dam

Time history of accelerations, velocity and displacement

Date: 16/10/2020 Job No. 109014.08

APPENDIX B-4

Loma Prieta, 18/10/1989, Point Bonita, 297 EQ Records-Matched



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Costerfield Dam

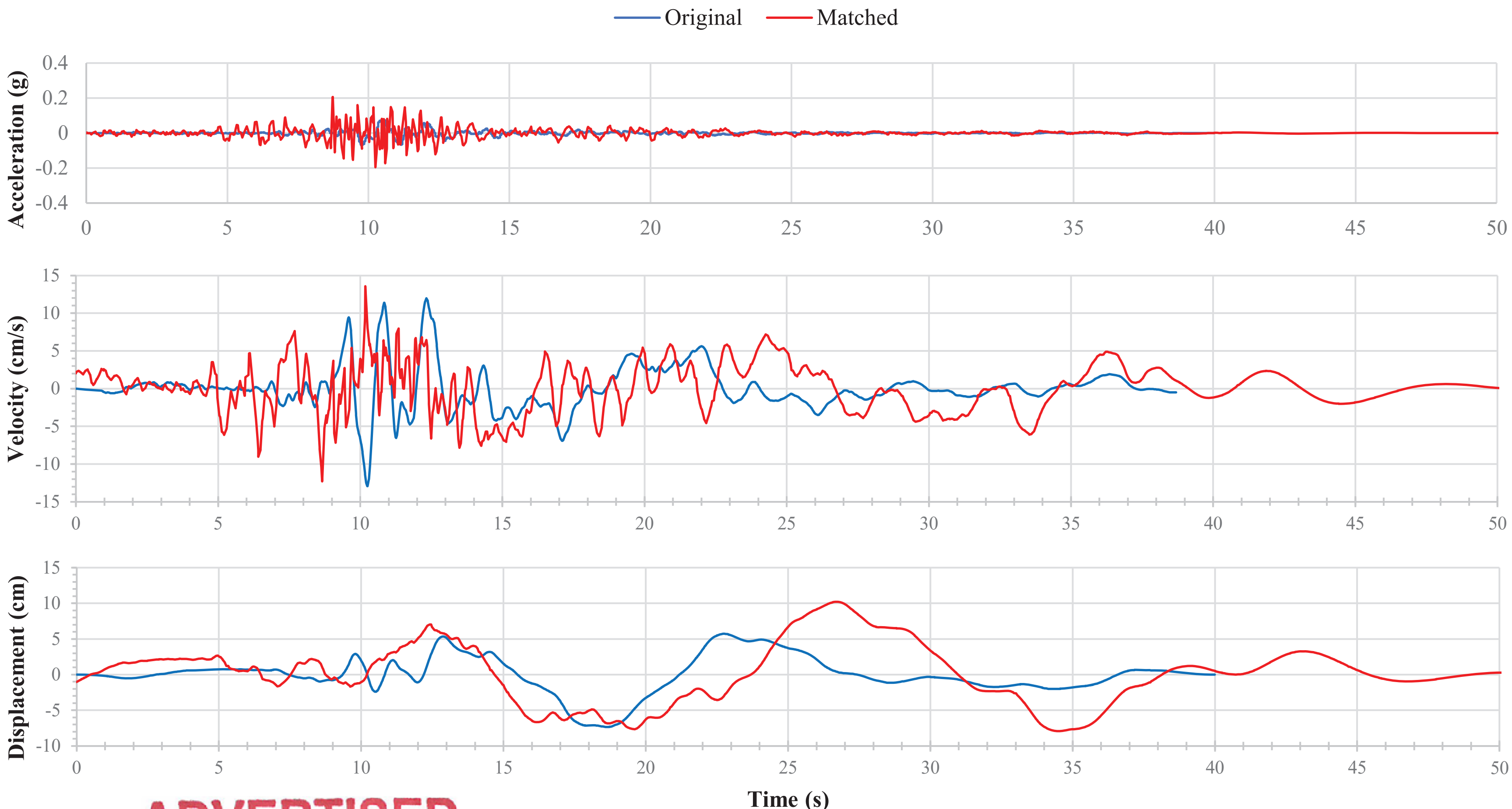
PSHA of Costerfield Dam

5,000 year UHS - Target vs Matched Spectra

Date: 16/10/2020 Job No. 109014.08

APPENDIX B-5

Loma Prieta, 18/10/1989, Point Bonita, 297 EQ Records-Matched



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Costerfield Dam

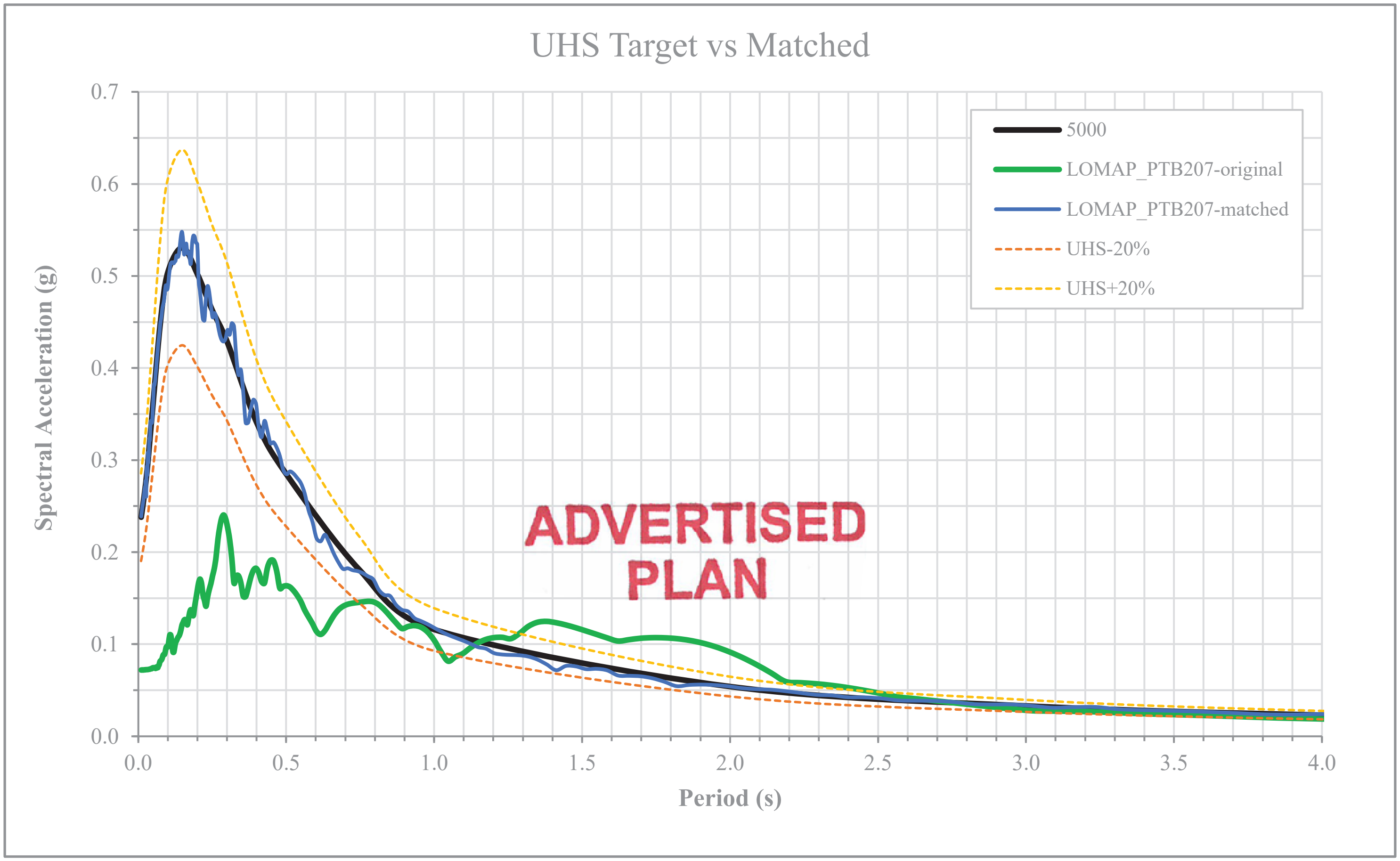
PSHA of Costerfield Dam

Time history of accelerations, velocity and displacement

Date: 16/10/2020 Job No. 109014.08

APPENDIX B-6

Loma Prieta, 18/10/1989, Point Bonita, 207 EQ Records-Matched



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Costerfield Dam

PSHA of Costerfield Dam

5,000 year UHS - Target vs Matched Spectra

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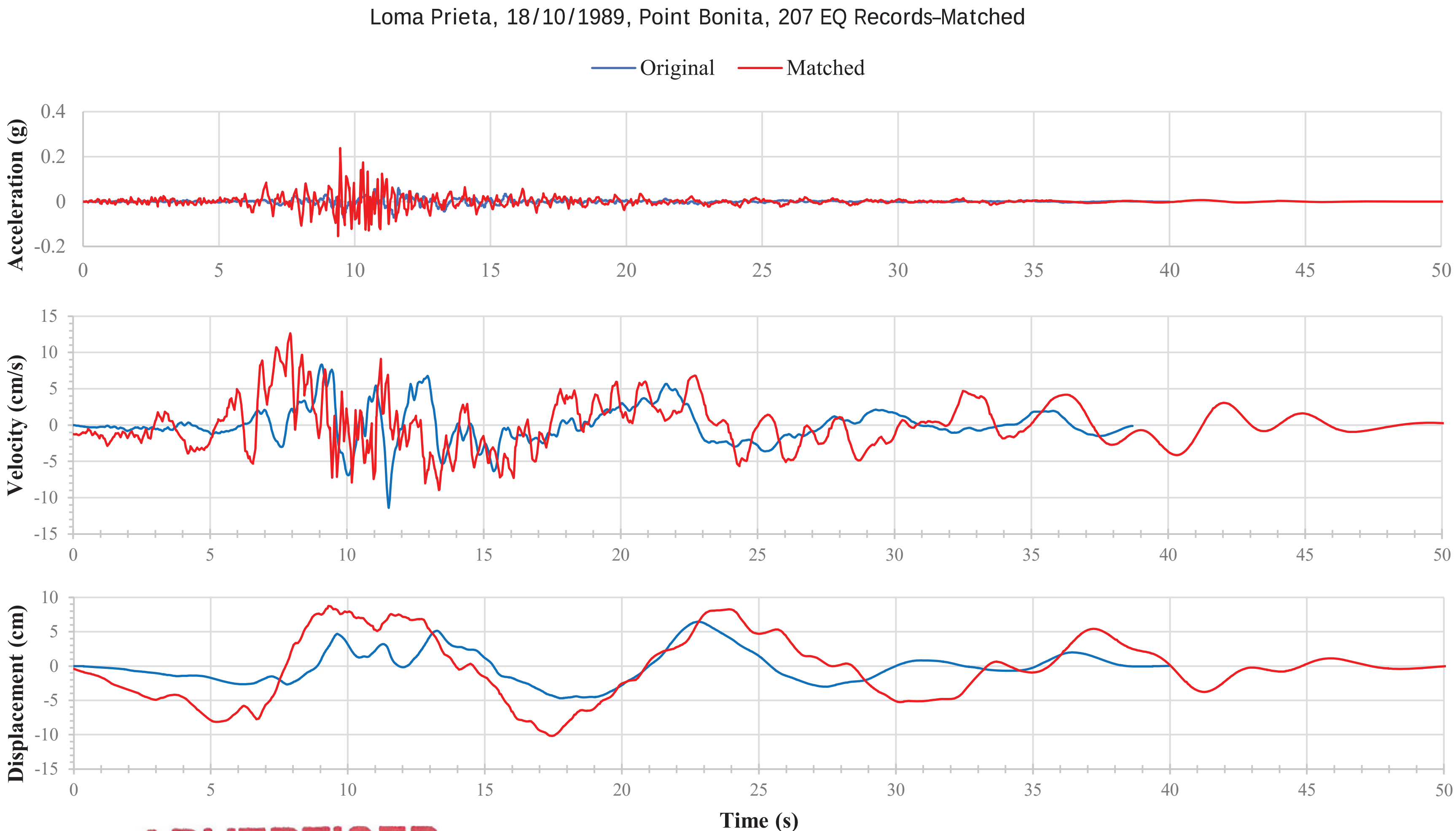
APPENDIX B-7



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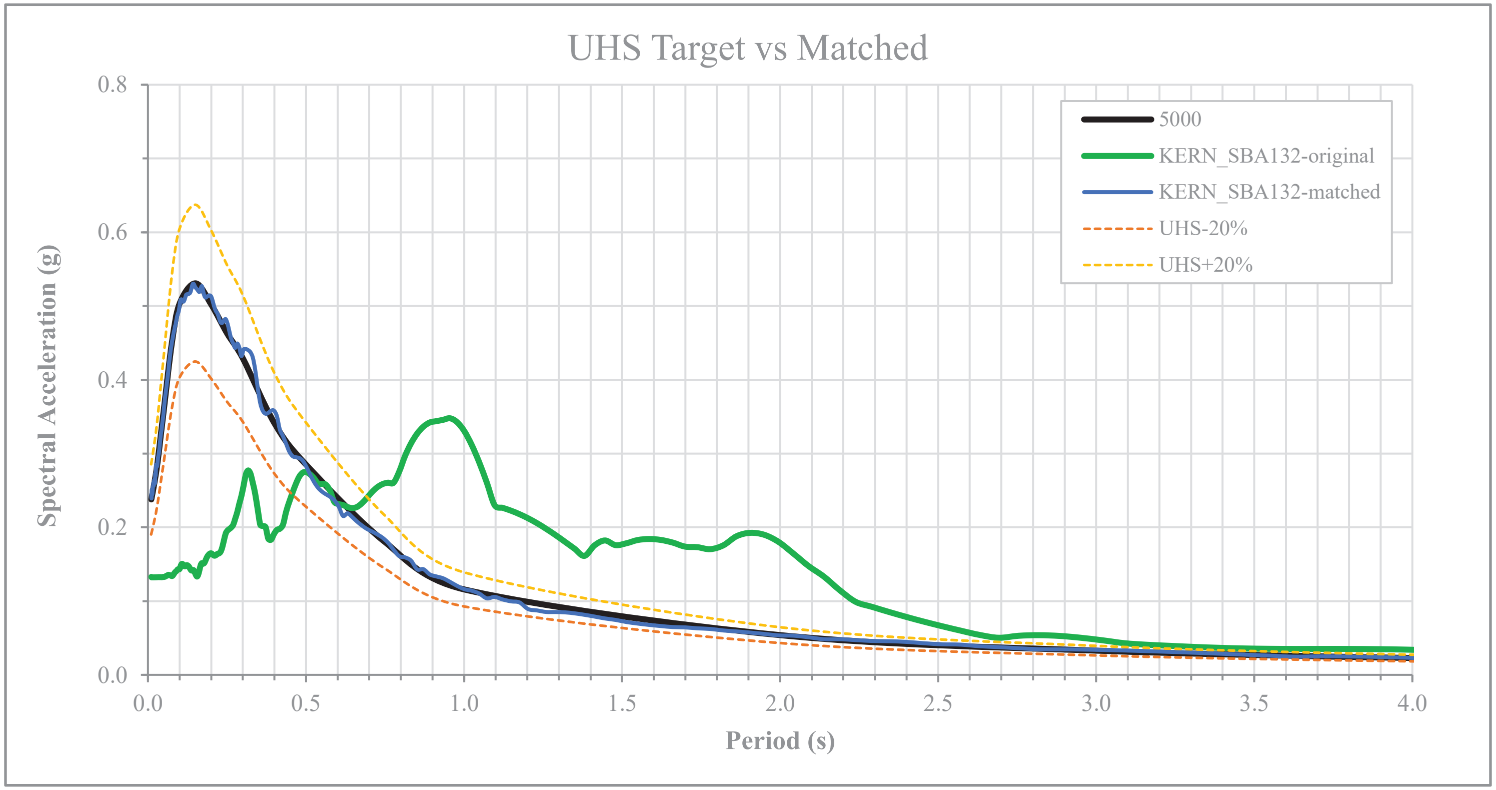
APPENDIX B-8

Kern County, 21/7/1952, Santa Barbara Courthouse, 132 EQ Records-Matched



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APPENDIX B-9

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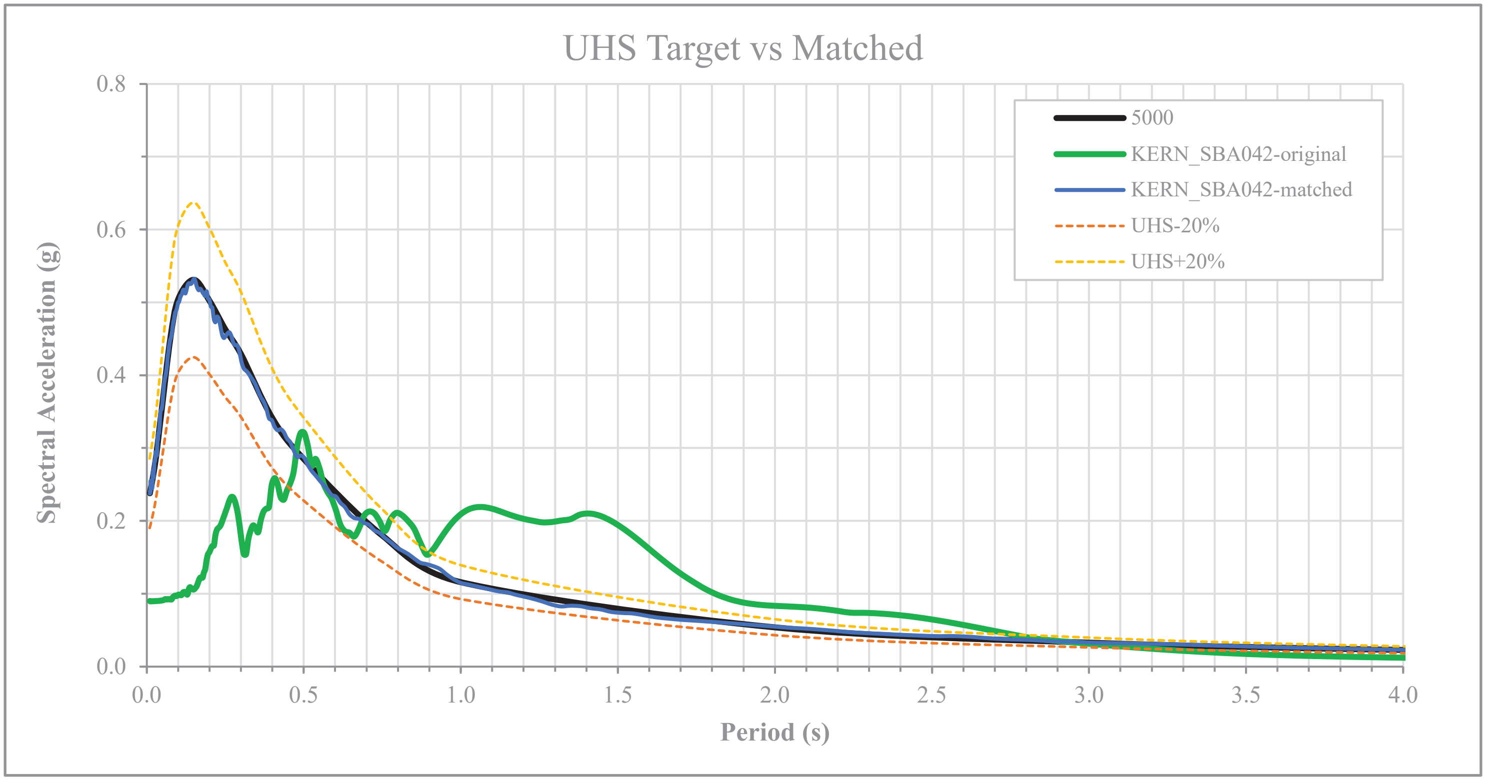
APPENDIX B-10

Kern County, 21/7/1952, Santa Barbara Courthouse, 42 EQ Records-Matched



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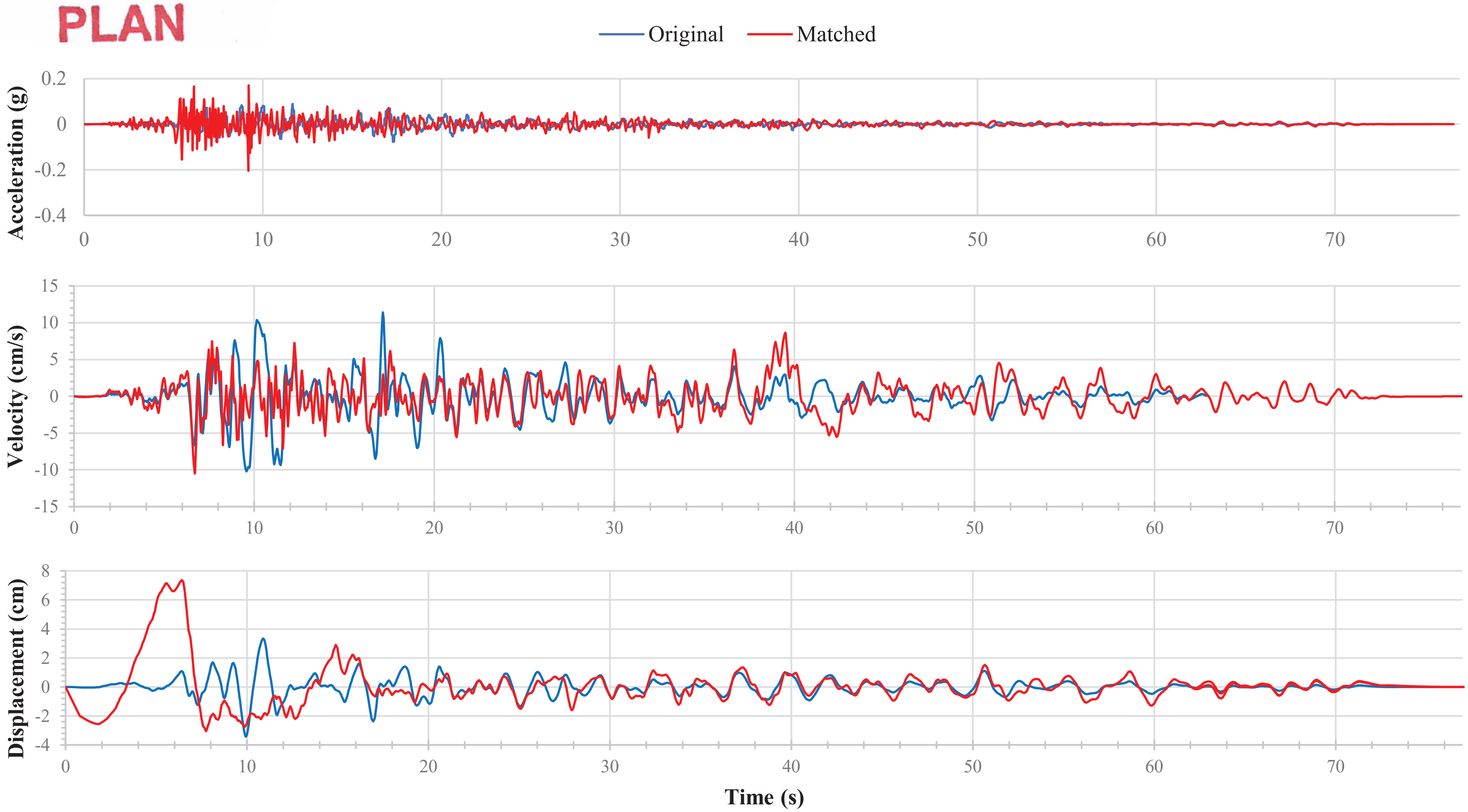
APPENDIX B-11

Kern County, 21/7/1952, Santa Barbara Courthouse, 42 EQ Records-Matched



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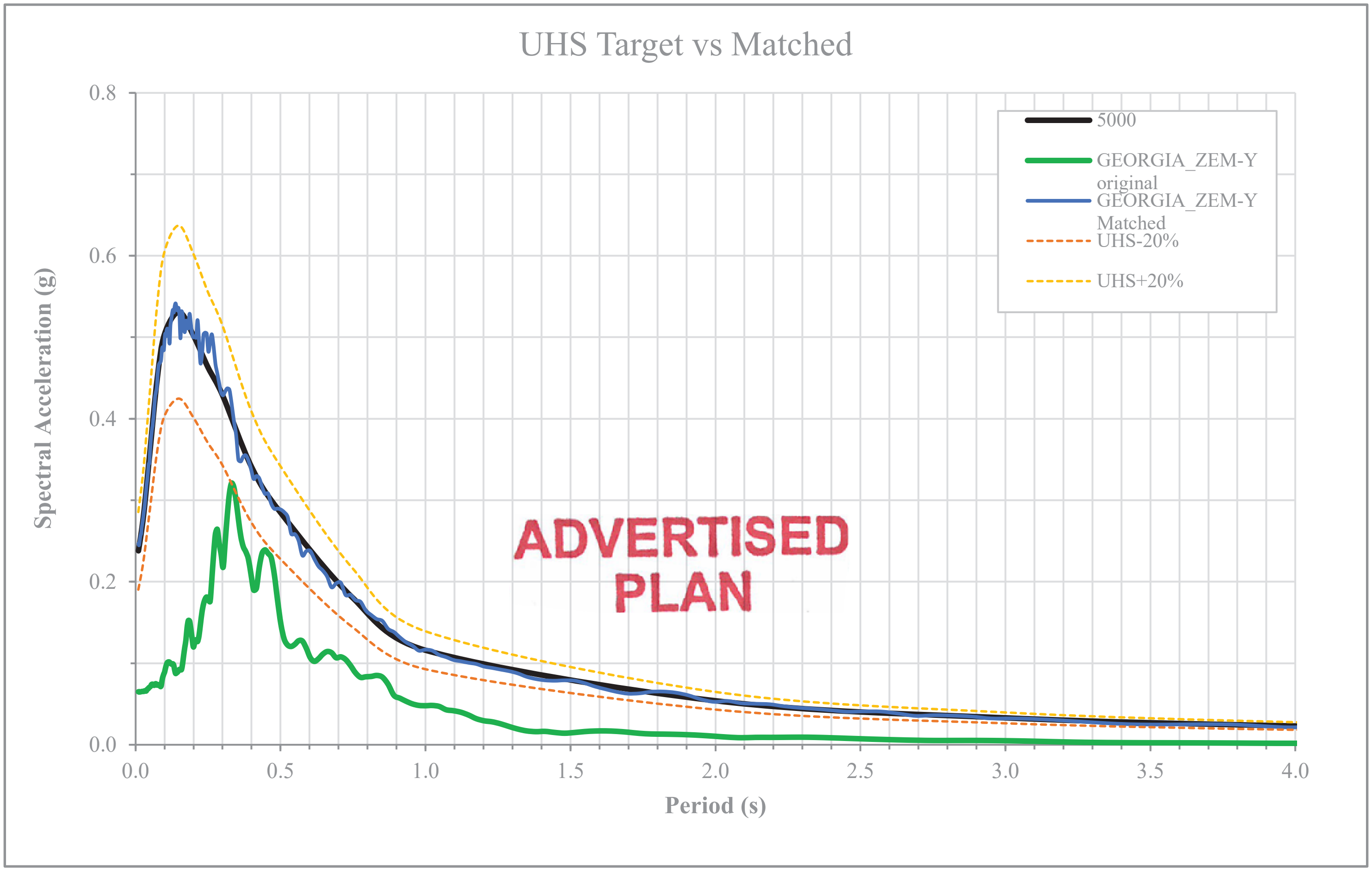
APPENDIX B-12

Georgia_ USSR, 29/4/1991, Zem, 90 EQ Records-Matched



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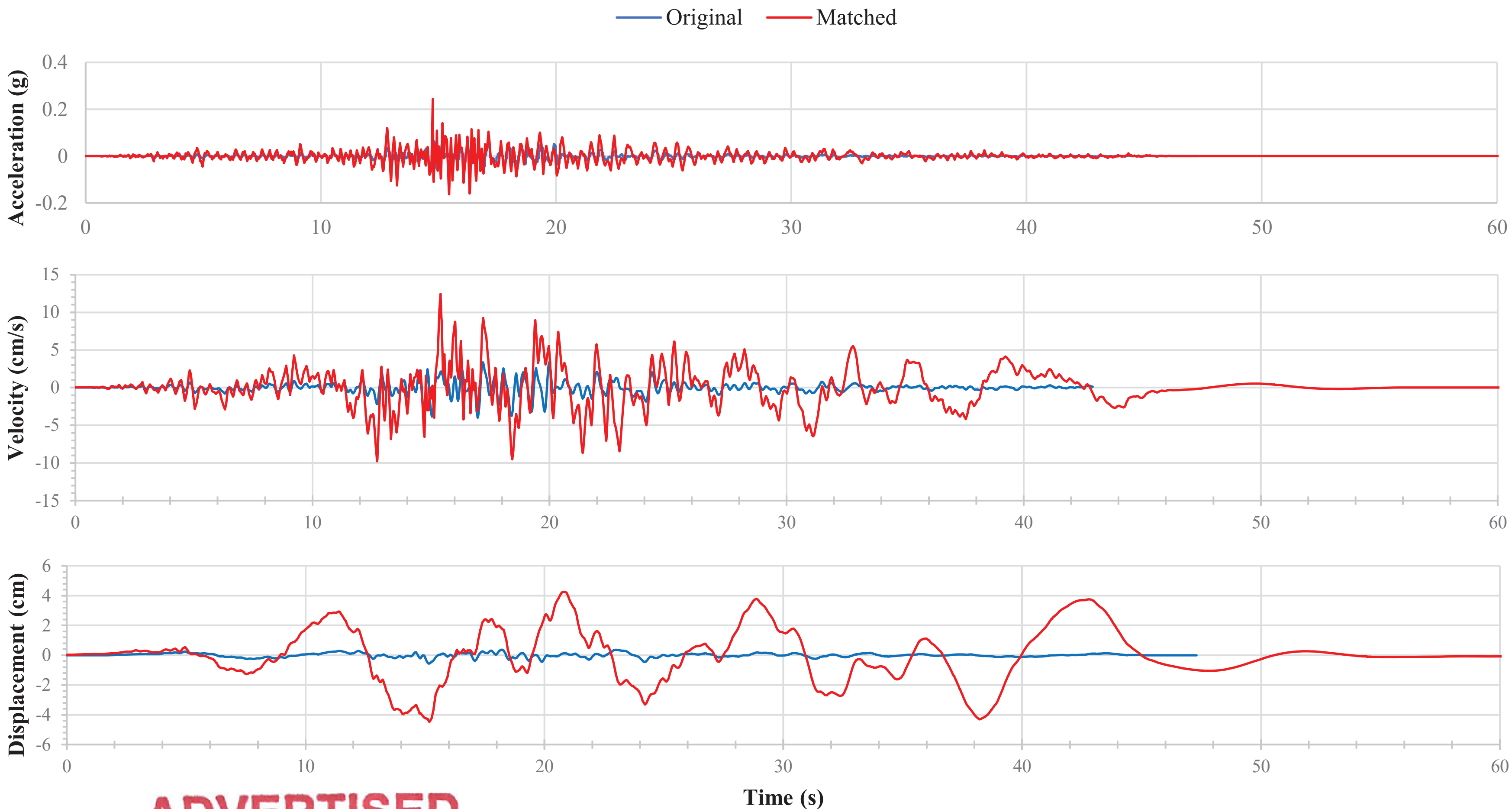
APPENDIX B-13

Georgia_ USSR, 29/4/1991, Zem, 90 EQ Records-Matched



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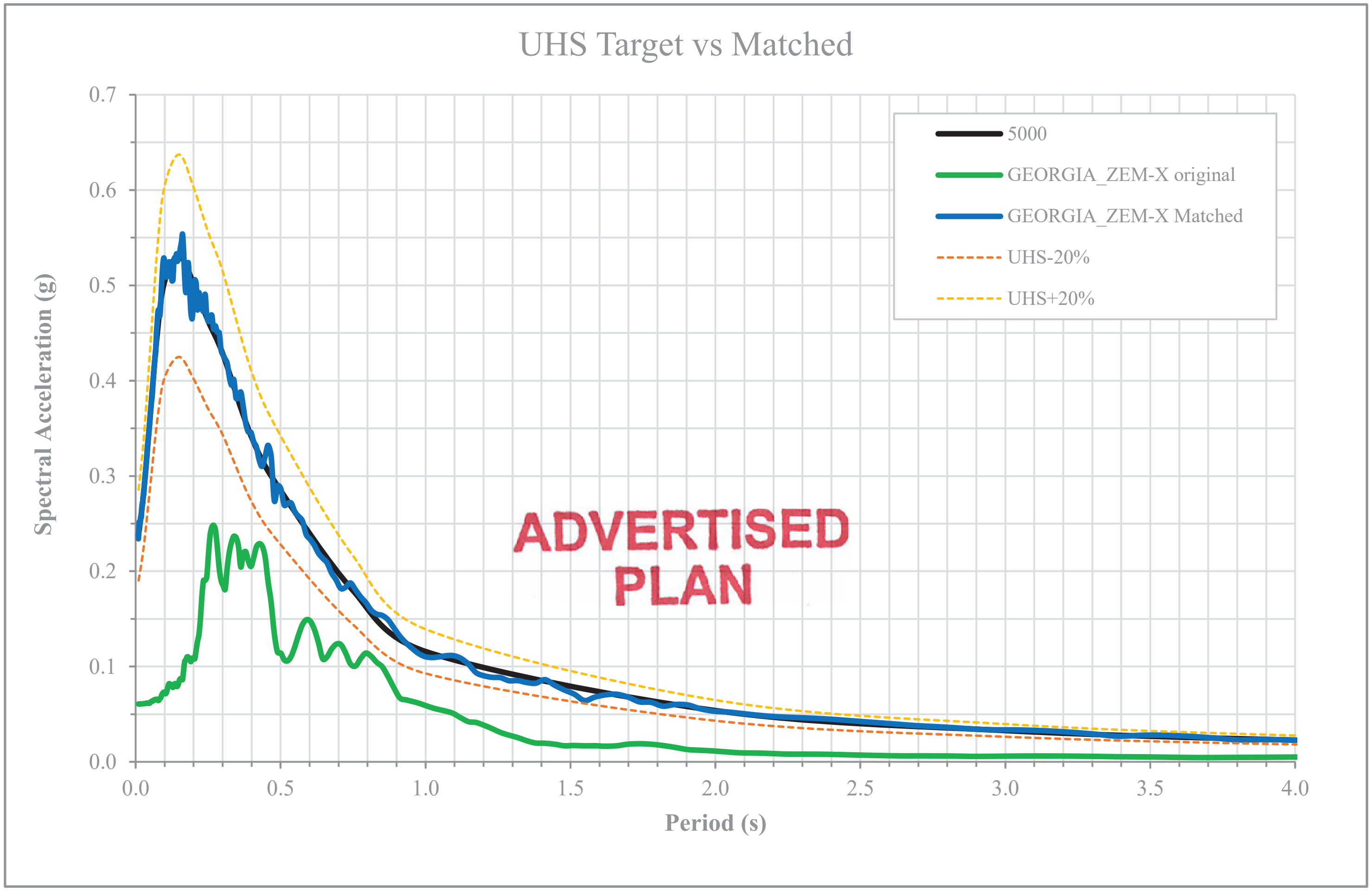
APPENDIX B-14

Georgia_ USSR, 29/4/1991, Zem, 00 EQ Records-Matched



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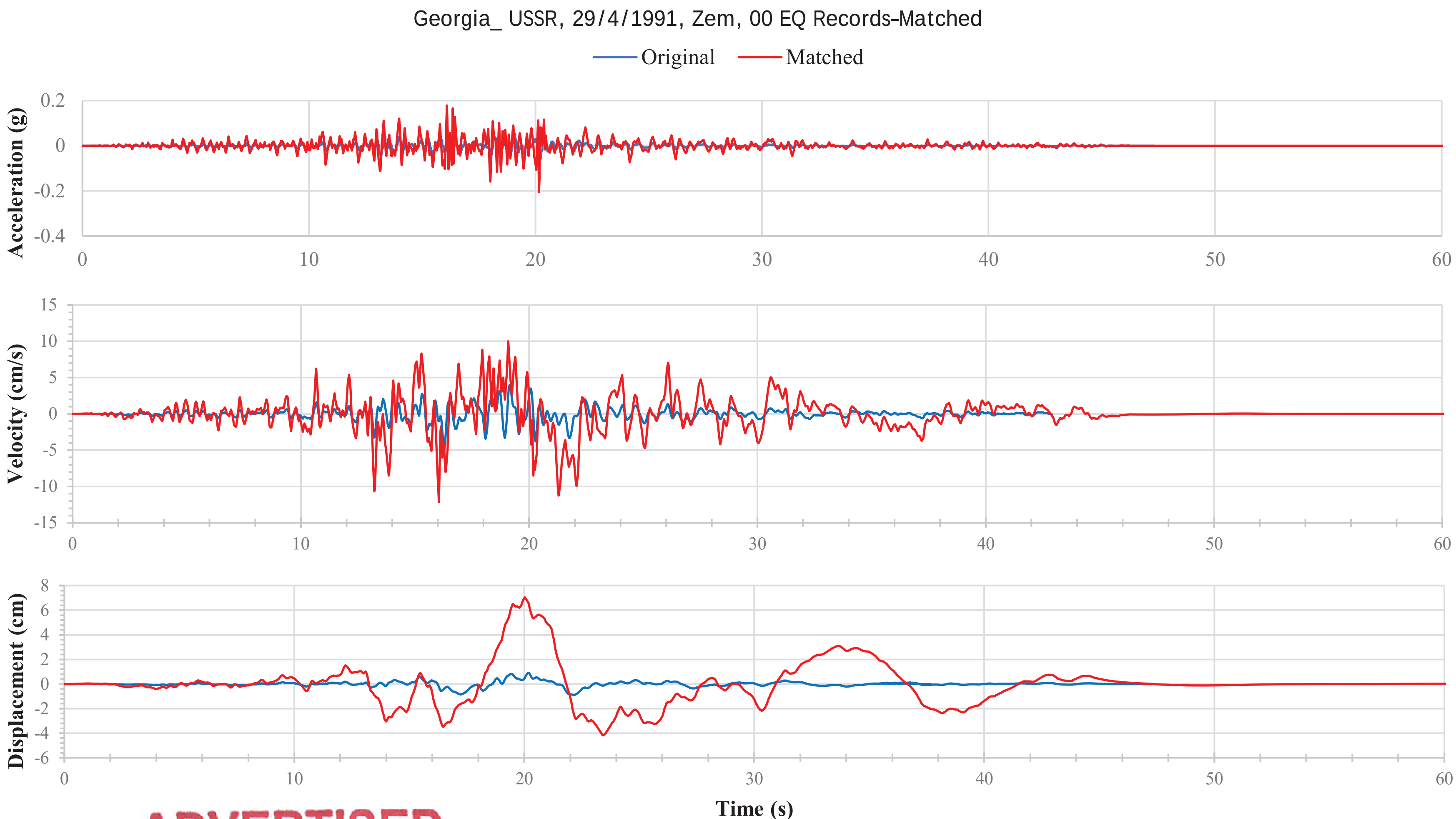
APPENDIX B-15



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APPENDIX B-16