Investigation of the Load Distribution of HDPE Mats Under Crane Outriggers

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Abstract

This study examines how high-density polyethylene (HDPE) mats, with their low flexural stiffness, affect the distribution of concentrated loads under crane outriggers. A case study comparing the analysis of beams on elastic foundations for the HDPE mat thicknesses 80, 80+80, 80+80+80 mm and 80 mm thick steel is presented.

Keywords: HDPE mats, bog-mats, timber mat, aluminium mat, outrigger, crane mat, crane outrigger mat, mobile crane, temporary works engineering

1. Introduction

High-density polyethylene (HDPE) is a robust and adaptable thermoplastic known for its high strength-to-density ratio and resistance to chemicals and moisture [1]. With a low cost and a high molecular weight, HDPE has become a popular choice in many industries, from consumer goods to civil engineering. Its versatility allows it to be shaped into piping, containers, geomembranes, and structural components, while its toughness and impact resistance makes it ideal for ground protection and foundation support. HDPE is widely used in construction because it is flexible and durable, but to understand its full potential, we need to examine how it behaves under different conditions, like stress and heavy loads. When compared to stiffer materials like steel, HDPE can offer unique benefits, though with varying pressure distribution. This comparison helps engineers select the most suitable materials for specific applications, ensuring safer and more efficient designs [2].

The function of a crane mat is to disperse the large outrigger load exerted by the crane into a uniformly distributed patch load on the ground. This necessitates that the outrigger mat possesses ample stiffness to spread the load across the intended area without excessive bending and deflection [3]. Different types of outrigger mats are accessible in the market, including steel, aluminium, timber, and HDPE (High-Density Polyethylene), each with its advantages and drawbacks. Steel, for instance, is the most rigid and effectively spreads the load, yet it is also the heaviest, requiring additional machinery for crane setup. In this brief, we will focus on HDPE mats.

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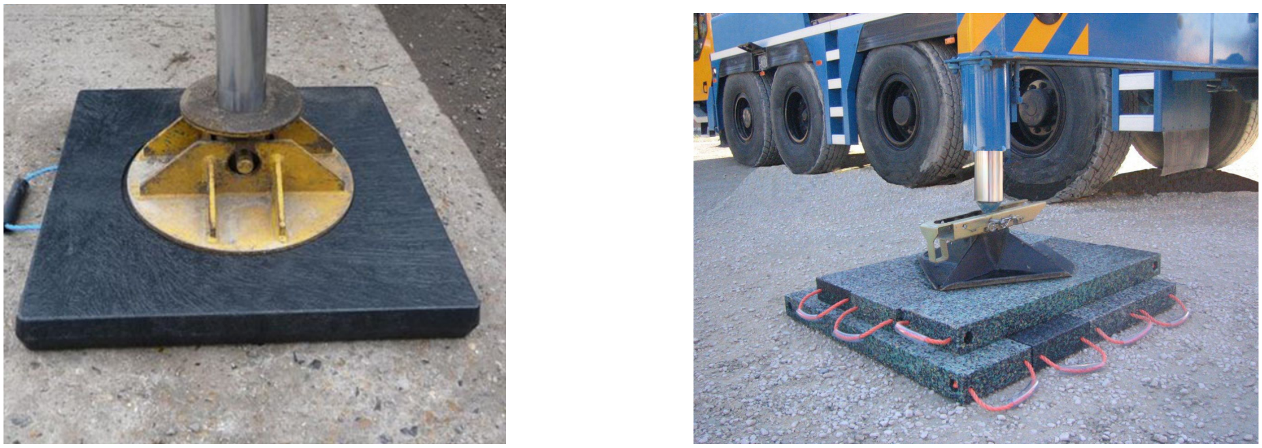


(a) Single layer mat.

(b) Double layer mat.

Figure 1: Double-layer mat ensures a more uniform distribution of pressure.

Initially, HDPE mats may seem highly attractive due to their durability, lightweight nature, widespread availability, and suppliers' claims of very high load capacities. However, HDPE possesses a relatively low modulus of elasticity (1200MPa) and low yield stress in bending (25MPa) [4]; raising concerns about the distribution of high concentrated loads due to the mats' low flexural stiffness. On a standard granular working platform, the inadequate flexural stiffness of an HDPE crane outrigger mat results in concentrated pressure beneath the crane's foot, particularly in the central area of the mat, rather than being uniformly spread across its entire surface.

2. Analysis and Results

This section presents sample model calculations involving the maximum ground pressure distribution of mat types and pressure distribution of HDPE mats of varying sizes along with their important parameters such as shear, moment, and bearing pressures. The sample provided in this study is for illustration purposes only and should not be used as a design guide.

2.1. Sample Calculation

A typical common problem at site is spreading a 20 t (200 kN) outrigger load into the ground. A 1 m HDPE mat has been selected for the demonstration purpose. Typical parameters used in the calculation are as follows:

- Modulus of elasticity (E) of HDPE mat = 1200 MPa for ordinary and 7200 MPa for shear-controlled orientation in injection molding (SCORIM) [1], which allows the production of very stiff molded parts,
- HDPE mat size = 1000x1000x80 mm,
- Crane outrigger foot size = 300x300 mm,
- Outrigger load = 200 kN,

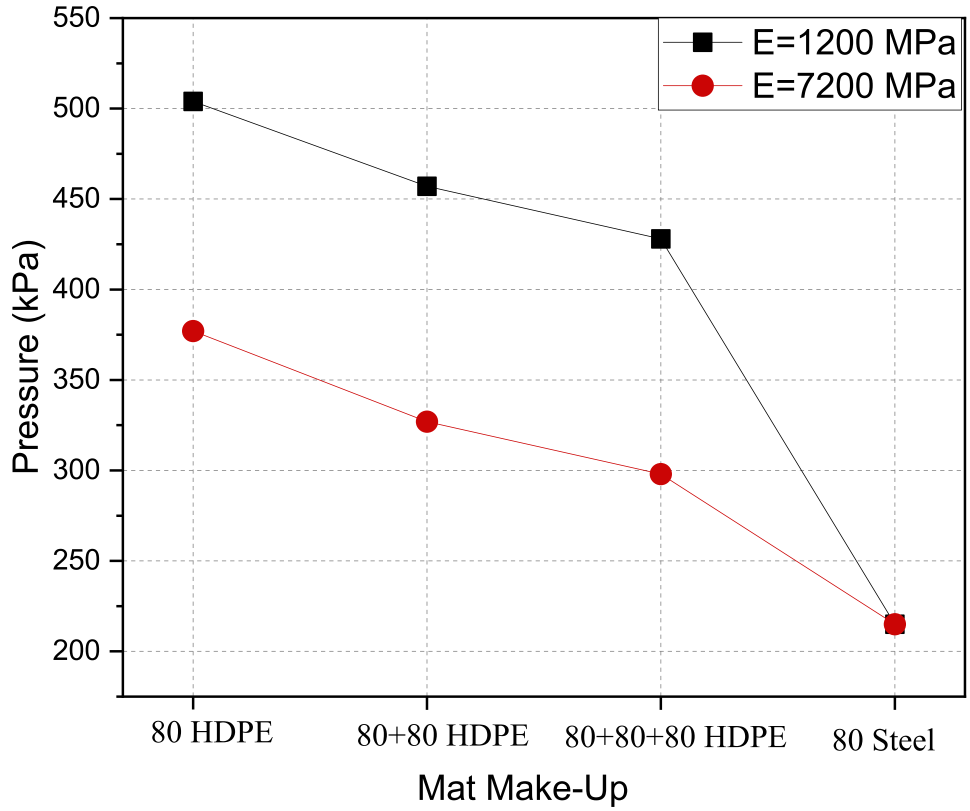


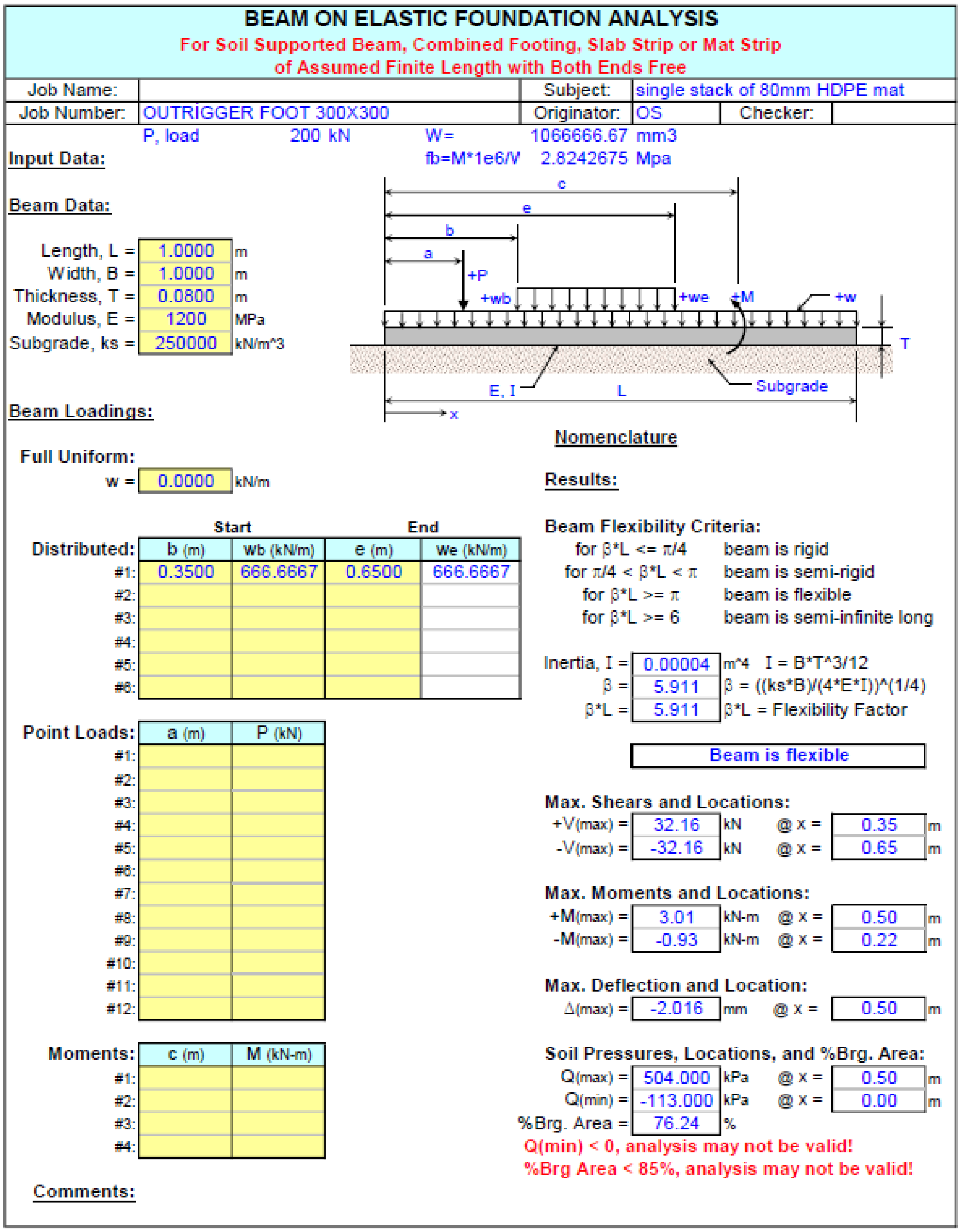
Figure 2: Maximum ground pressure at the centre of mat vs mat type is shown. Certain assumptions are made in calculating the maximum pressures. For example, bearing pressure is linearly proportional to the deflection and varies as a function of subgrade modulus, K. For simplicity models are treated as one-dimensional beams and not two-dimensional plates. It is evident that with the increased number of HDPE mat layers and increased modulus of elasticity the pressure distribution gets closer to that of stiffer steel mat.

– The modulus of subgrade reaction, K=250 $kN/m^2/mm$ (typical for compacted well-graded granular material). This figure is an estimated relationship of how the ground will settle under a distributed load i.e. 250 kN over 1 meter square area the ground is anticipated to settle 1mm.

The depicted maximum ground pressures in Fig. 2 represent the pressures at the mat's center, which notably exceed the assumption of achieving uniform pressure distribution across the entire mat , i.e. 200 kN/m^2. HDPE has a relatively low stiffness and thus it will produce high pressures at the centre and less at the edges. This effect is reduced with the increase in the number of mat layers and increase in modulus of elasticity (see Fig.2). Concentrated pressure at the central area may pose a risk of ground bearing failure. Users are advised to confirm the Modulus of Elasticity of the HDPE mats as there are some mats in the market made out of material with low Modulus of Elasticity.
Caution should be exercised when relying on information from HDPE mat suppliers' websites. Some suppliers claim that a single 3m by 1m 100mm thick HDPE mat can support a load of 100t; however, achieving this capacity requires multiple layers, not a single layer. When opting for this type of mat, reduced loadings due to reduced effective bearing areas must be taken into account. It is advisable to seek additional guidance from a qualified engineer.

2.2. Beam on Elastic Foundation Analysis

This section examines HDPE mats of varying sizes in the context of beam-on-elastic-foundation analysis. Shear, moment, and bearing pressure diagrams are generated from the analysis, revealing that thicker mats result in reduced pressure at the centre. However, it is difficult to draw a definitive conclusion about the uniformity of pressure distribution beneath HDPE mats. Additionally, the analysis of the 80 mm thick steel mat is done, and the results are presented for comparison. Calculations are done using Beam On Elastic Foundation Analysis (BOEF 1.6) spreadsheet program which is written in MS-Excel for the purpose of analysis of a finite length beam with free ends supported continuously on an elastic foundation [5]. Note that the solutions presented in the following pages are approximate and for comparison purposes only.



BEAM ON ELASTIC FOUNDATION ANALYSIS

For Soil Supported Beam, Combined Footing, Slab Strip or Mat Strip
of Assumed Finite Length with Both Ends Free

Job Name:		Subject:	single stack of 80mm HDPE mat		
Job Number:	OUTRIGGER FOOT 300X300	Originator:	OS	Checker:	

P, load 200 kN W= 1066666.67 mm3
fb=M*1e6/W 2.8242675 Mpa

Input Data:

Beam Data:

Length, L =	1.0000	m
Width, B =	1.0000	m
Thickness, T =	0.0800	m
Modulus, E =	1200	MPa
Subgrade, ks =	250000	kN/m^3

Nomenclature

Beam Loadings:

Full Uniform:
w = 0.0000 kN/m

Distributed:	Start b (m)	Start Wb (kN/m)	End e (m)	End We (kN/m)
#1:	0.3500	666.6667	0.6500	666.6667
#2:				
#3:				
#4:				
#5:				
#6:				

Point Loads:	a (m)	P (kN)
#1:		
#2:		
#3:		
#4:		
#5:		
#6:		
#7:		
#8:		
#9:		
#10:		
#11:		
#12:		

Moments:	c (m)	M (kN-m)
#1:		
#2:		
#3:		
#4:		

Comments:

Results:

Beam Flexibility Criteria:

for β*L <= π/4	beam is rigid
for π/4 < β*L < π	beam is semi-rigid
for β*L >= π	beam is flexible
for β*L >= 6	beam is semi-infinite long

Inertia, I =	0.00004	m^4	I = B*T^3/12
β =	5.911		β = ((ks*B)/(4*E*I))^(1/4)
β*L =	5.911		β*L = Flexibility Factor

Beam is flexible

Max. Shears and Locations:

+V(max) =	32.16	kN	@ x =	0.35	m
-V(max) =	-32.16	kN	@ x =	0.65	m

Max. Moments and Locations:

+M(max) =	3.01	kN-m	@ x =	0.50	m
-M(max) =	-0.93	kN-m	@ x =	0.22	m

Max. Deflection and Location:

Δ(max) =	-2.016	mm	@ x =	0.50	m

Soil Pressures, Locations, and %Brg. Area:

Q(max) =	504.000	kPa	@ x =	0.50	m
Q(min) =	-113.000	kPa	@ x =	0.00	m
%Brg. Area =	76.24	%			

Q(min) < 0, analysis may not be valid!
%Brg Area < 85%, analysis may not be valid!

Figure 3: Analysis of the 80 mm thick HDPE mat with E=1200 MPa.

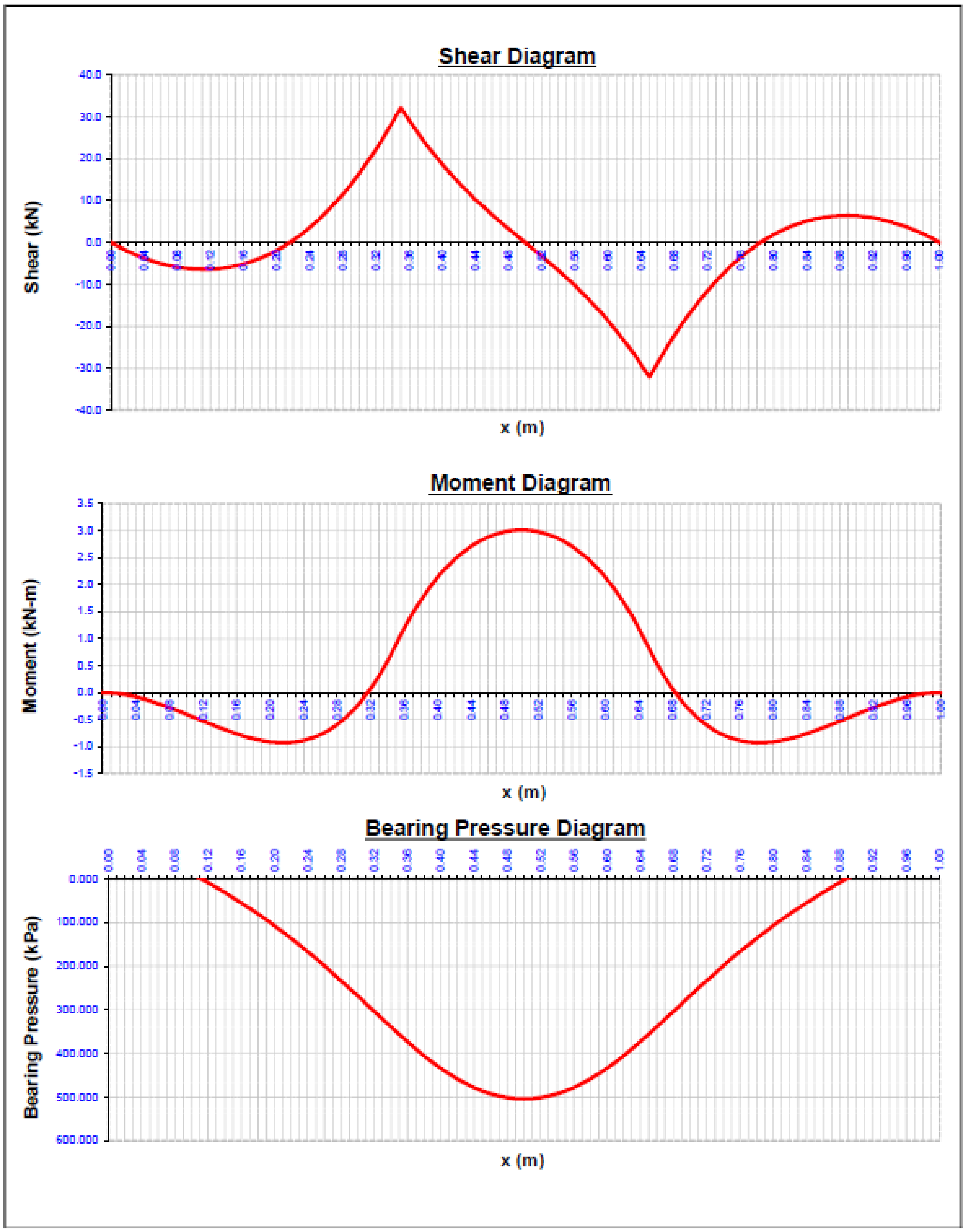


Figure 4: Shear, moment, and pressure distribution for the 80 mm thick HDPE mat with E=1200 MPa.

BEAM ON ELASTIC FOUNDATION ANALYSIS

For Soil Supported Beam, Combined Footing, Slab Strip or Mat Strip
of Assumed Finite Length with Both Ends Free

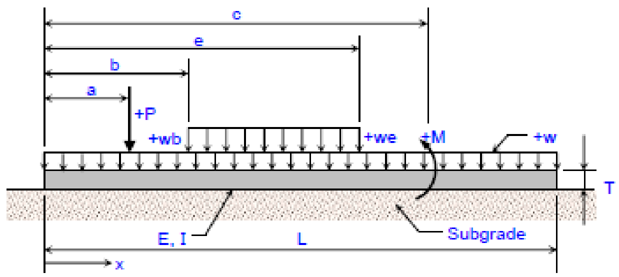
Job Name:		Subject:	DOUBLE stack of 80mm HDPE mat		
Job Number:	OUTRIGGER FOOT 300X300	Originator:	OS	Checker:	

P, load 200 kN W= 1666666.67 mm3
fb=M*1e6/W 2.619633 Mpa

Input Data:

Beam Data:

Length, L =	1.0000	m
Width, B =	1.0000	m
Thickness, T =	0.1000	m
Modulus, E =	1200	MPa
Subgrade, ks =	250000	kN/m^3



Nomenclature

Beam Loadings:

Full Uniform:

w = 0.0000 kN/m

Distributed:

	Start		End	
	b (m)	wb (kN/m)	e (m)	we (kN/m)
#1:	0.3500	666.6667	0.6500	666.6667
#2:				
#3:				
#4:				
#5:				
#6:				

Point Loads:

	a (m)	P (kN)
#1:		
#2:		
#3:		
#4:		
#5:		
#6:		
#7:		
#8:		
#9:		
#10:		
#11:		
#12:		

Moments:

	c (m)	M (kN-m)
#1:		
#2:		
#3:		
#4:		

Comments:

Results:

Beam Flexibility Criteria:

for β*L <= π/4	beam is rigid
for π/4 < β*L < π	beam is semi-rigid
for β*L >= π	beam is flexible
for β*L >= 6	beam is semi-infinite long

Inertia, I =	0.00008	m^4	I = B*T^3/12
β =	5.000		β = ((ks*B)/(4*E*I))^(1/4)
β*L =	5.000		β*L = Flexibility Factor

Beam is flexible

Max. Shears and Locations:

+V(max) =	37.20	kN	@ x =	0.35	m
-V(max) =	-37.20	kN	@ x =	0.65	m

Max. Moments and Locations:

+M(max) =	4.37	kN-m	@ x =	0.50	m
-M(max) =	-0.70	kN-m	@ x =	0.19	m

Max. Deflection and Location:

Δ(max) =	-1.829	mm	@ x =	0.50	m

Soil Pressures, Locations, and %Brg. Area:

Q(max) =	457.250	kPa	@ x =	0.50	m
Q(min) =	-114.250	kPa	@ x =	0.00	m
%Brg. Area =	80.20	%			

Q(min) < 0, analysis may not be valid!
%Brg Area < 85%, analysis may not be valid!

Figure 5: Analysis of the HDPE mat 80+80 thick (equivalent thickness: 100 mm) with E=1200 MPa.

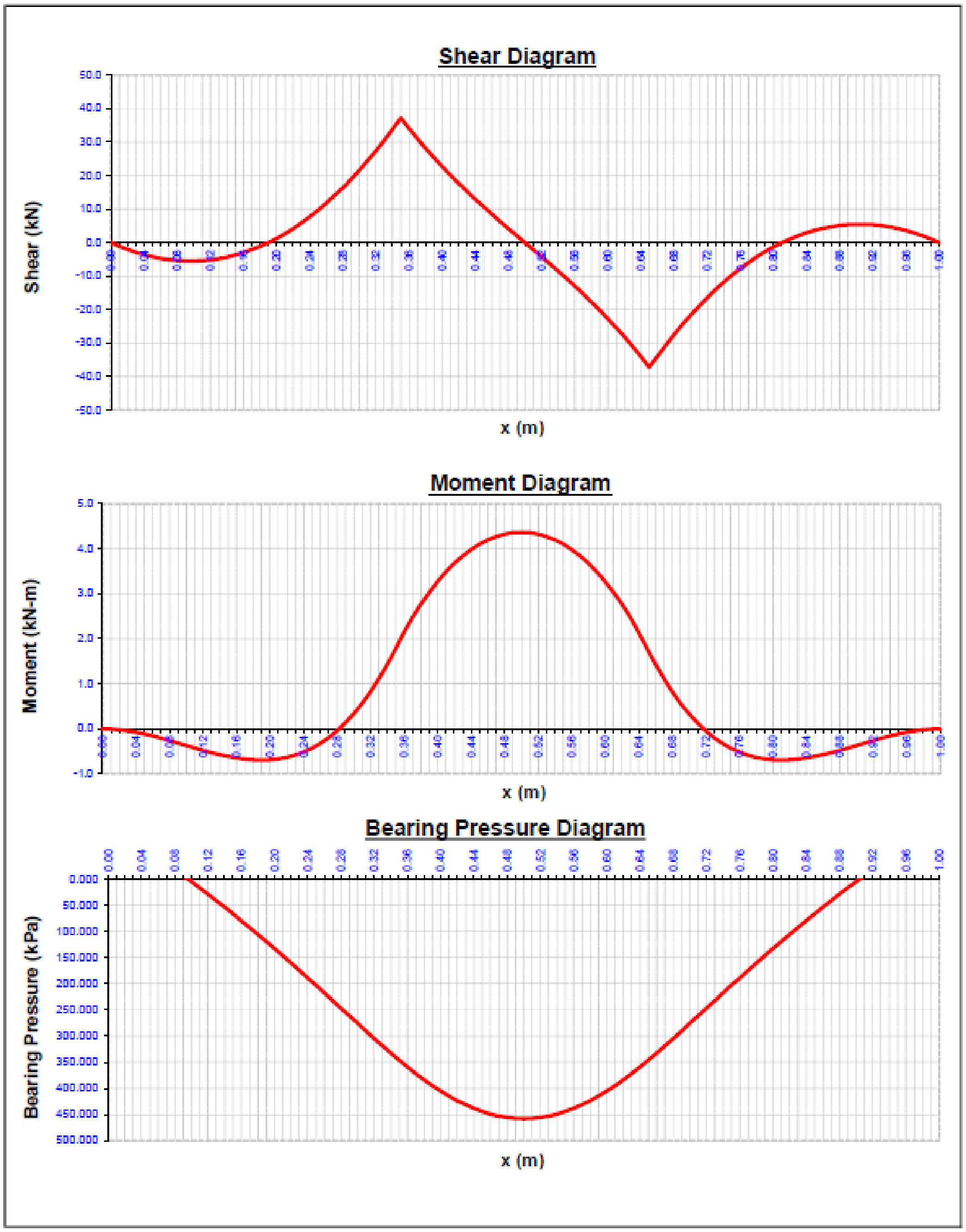


Figure 6: Shear, moment, and pressure distribution for the HDPE mat 80+80 thick (equivalent thickness: 100 mm) with E=1200 MPa.

BEAM ON ELASTIC FOUNDATION ANALYSIS

For Soil Supported Beam, Combined Footing, Slab Strip or Mat Strip of Assumed Finite Length with Both Ends Free

Job Name:		Subject:	TRIPLE stack of 80mm HDPE mat		
Job Number:	OUTRIGGER FOOT 300X300	Originator:	OS	Checker:	

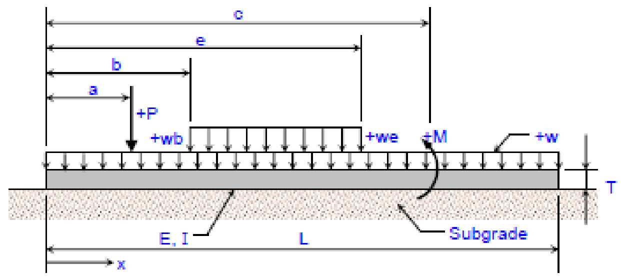
P, load 200 kN W= 2204166.67 mm3

fb=M*1e6/V 2.48839758 Mpa

Input Data:

Beam Data:

Length, L =	1.0000	m
Width, B =	1.0000	m
Thickness, T =	0.1150	m
Modulus, E =	1200	MPa
Subgrade, ks =	250000	kN/m^3



Nomenclature

Beam Loadings:

Full Uniform:

w = 0.0000 kN/m

Distributed:

	Start		End	
	b (m)	wb (kN/m)	e (m)	we (kN/m)
#1:	0.3500	666.6667	0.6500	666.6667
#2:				
#3:				
#4:				
#5:				
#6:				

Point Loads:

	a (m)	P (kN)
#1:		
#2:		
#3:		
#4:		
#5:		
#6:		
#7:		
#8:		
#9:		
#10:		
#11:		
#12:		

Moments:

	c (m)	M (kN-m)
#1:		
#2:		
#3:		
#4:		

Comments:

Results:

Beam Flexibility Criteria:

for β*L <= π/4	beam is rigid
for π/4 < β*L < π	beam is semi-rigid
for β*L >= π	beam is flexible
for β*L >= 6	beam is semi-infinite long

Inertia, I =	0.00013	m^4	I = B*T^3/12
β =	4.502		β = ((ks*B)/(4*E*I))^(1/4)
β*L =	4.502		β*L = Flexibility Factor

Beam is flexible

Max. Shears and Locations:

+V(max) =	40.60	kN	@ x =	0.35	m
-V(max) =	-40.60	kN	@ x =	0.65	m

Max. Moments and Locations:

+M(max) =	5.48	kN-m	@ x =	0.50	m
-M(max) =	-0.46	kN-m	@ x =	0.17	m

Max. Deflection and Location:

Δ(max) =	-1.713	mm	@ x =	0.50	m

Soil Pressures, Locations, and %Brg. Area:

Q(max) =	428.250	kPa	@ x =	0.50	m
Q(min) =	-99.750	kPa	@ x =	0.00	m
%Brg. Area =	82.18	%			

Q(min) < 0, analysis may not be valid!

%Brg Area < 85%, analysis may not be valid!

Figure 7: Analysis of the HDPE mat 80+80+80 thick (equivalent thickness: 115 mm) with E=1200 MPa.

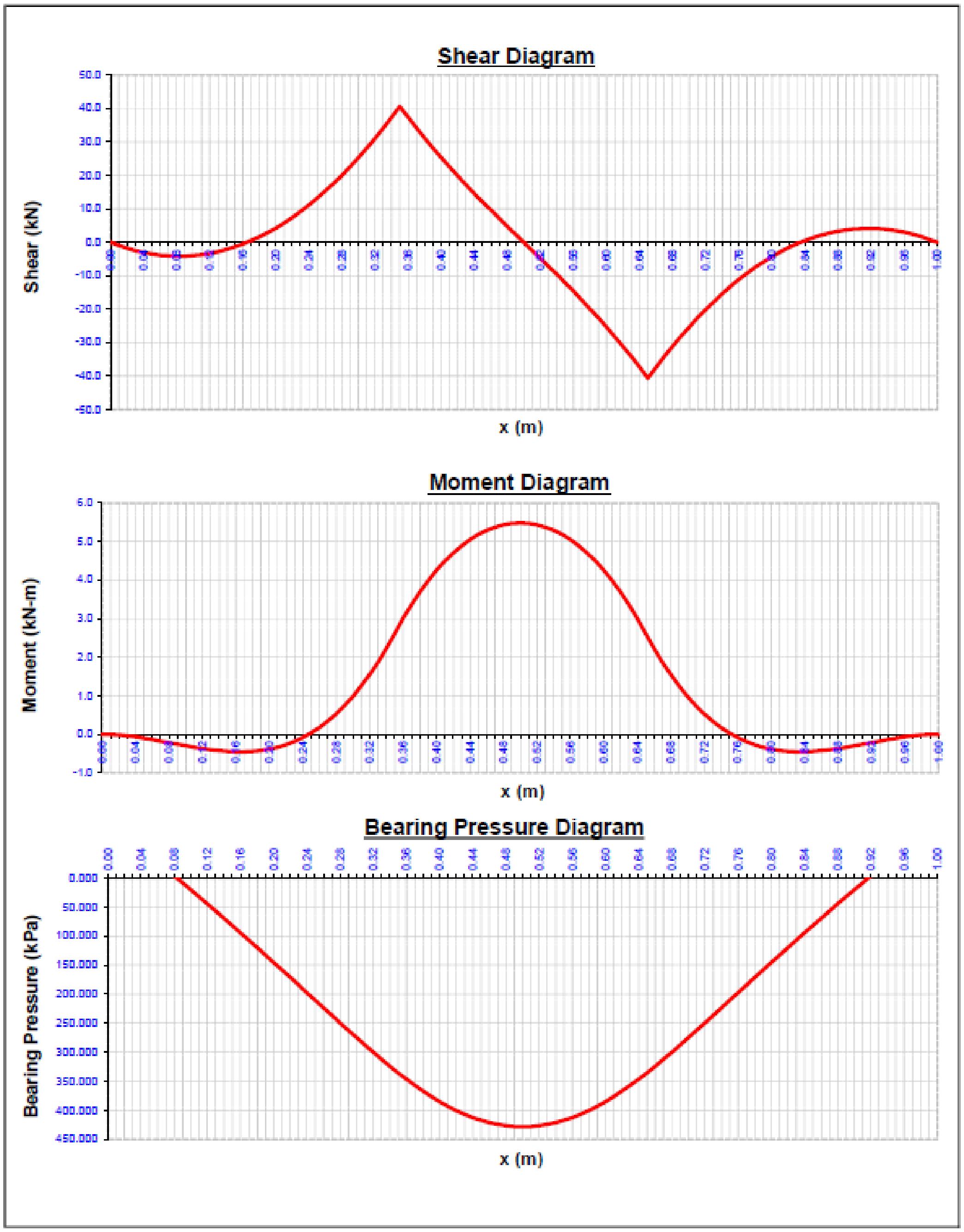
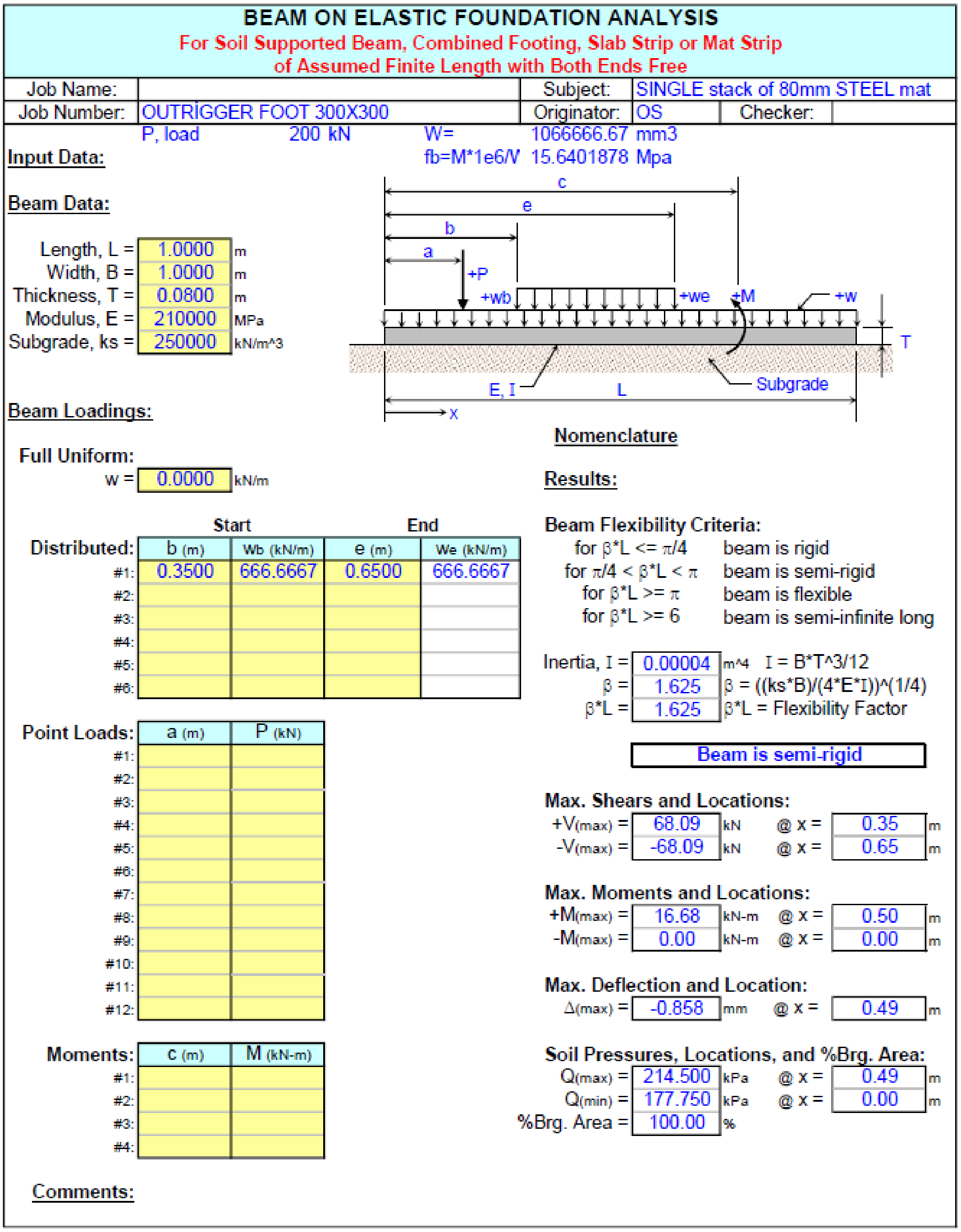


Figure 8: Shear, moment, and pressure distribution for the HDPE mat 80+80+80 thick (equivalent thickness: 115 mm) with E=1200 MPa.



BEAM ON ELASTIC FOUNDATION ANALYSIS
For Soil Supported Beam, Combined Footing, Slab Strip or Mat Strip
of Assumed Finite Length with Both Ends Free

Job Name:		Subject:	SINGLE stack of 80mm STEEL mat		
Job Number:	OUTRIGGER FOOT 300X300	Originator:	OS	Checker:	

P, load 200 kN W= 1066666.67 mm3
fb=M*1e6/V 15.6401878 Mpa

Input Data:

Beam Data:

Length, L =	1.0000	m
Width, B =	1.0000	m
Thickness, T =	0.0800	m
Modulus, E =	210000	MPa
Subgrade, ks =	250000	kN/m^3

Nomenclature

Beam Loadings:

Full Uniform:
w = 0.0000 kN/m

Distributed:	Start b (m)	Start Wb (kN/m)	End e (m)	End We (kN/m)
#1:	0.3500	666.6667	0.6500	666.6667
#2:				
#3:				
#4:				
#5:				
#6:				

Point Loads:	a (m)	P (kN)
#1:		
#2:		
#3:		
#4:		
#5:		
#6:		
#7:		
#8:		
#9:		
#10:		
#11:		
#12:		

Moments:	c (m)	M (kN-m)
#1:		
#2:		
#3:		
#4:		

Comments:

Results:

Beam Flexibility Criteria:
for β*L <= π/4 beam is rigid
for π/4 < β*L < π beam is semi-rigid
for β*L >= π beam is flexible
for β*L >= 6 beam is semi-infinite long

Inertia, I =	0.00004	m^4	I = B*T^3/12
β =	1.625		β = ((ks*B)/(4*E*I))^(1/4)
β*L =	1.625		β*L = Flexibility Factor

Beam is semi-rigid

Max. Shears and Locations:

+V(max) =	68.09	kN	@ x =	0.35	m
-V(max) =	-68.09	kN	@ x =	0.65	m

Max. Moments and Locations:

+M(max) =	16.68	kN-m	@ x =	0.50	m
-M(max) =	0.00	kN-m	@ x =	0.00	m

Max. Deflection and Location:

Δ(max) =	-0.858	mm	@ x =	0.49	m

Soil Pressures, Locations, and %Brg. Area:

Q(max) =	214.500	kPa	@ x =	0.49	m
Q(min) =	177.750	kPa	@ x =	0.00	m
%Brg. Area =	100.00	%			

Figure 9: Analysis of the 80 mm thick steel mat.

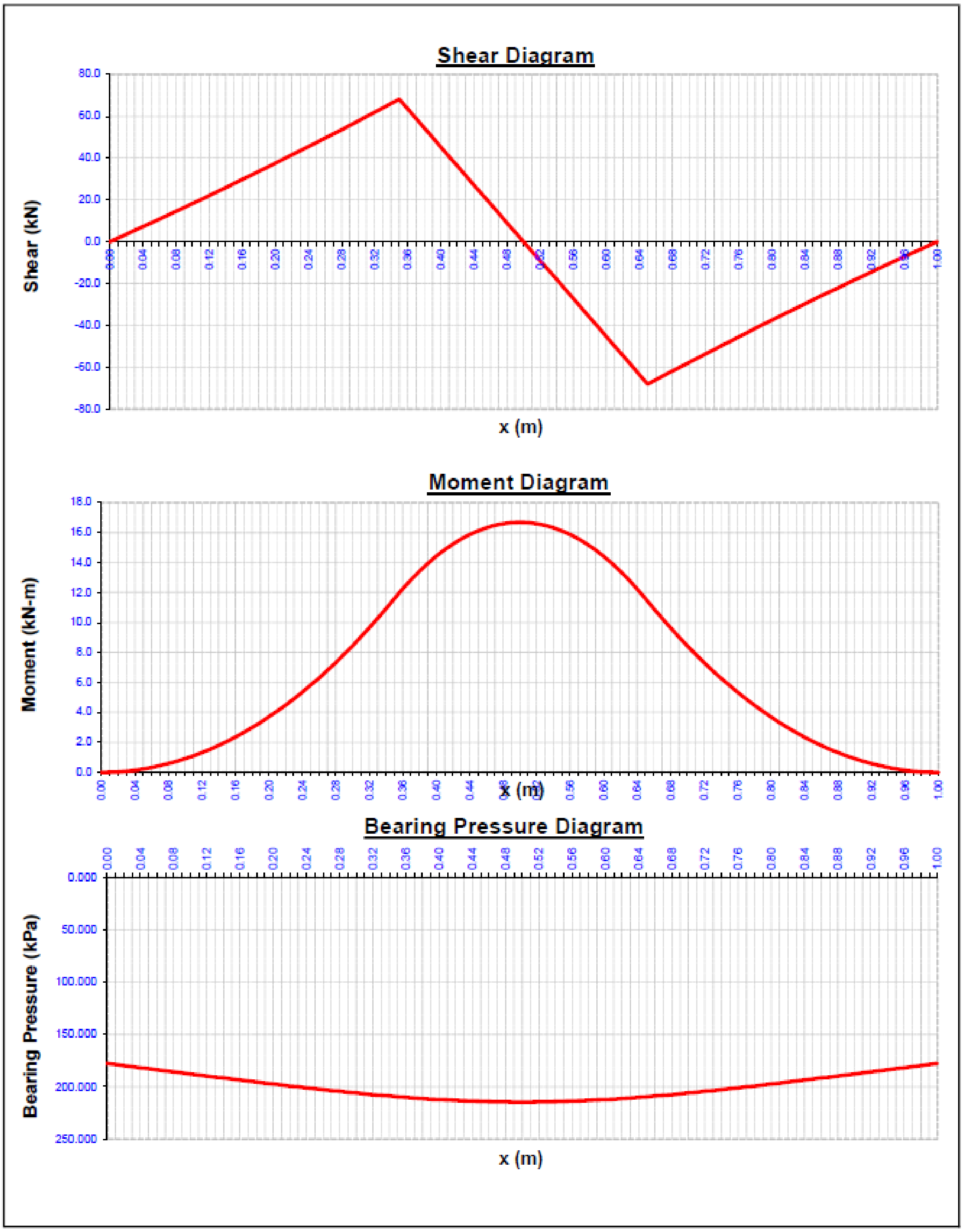


Figure 10: Shear, moment, and pressure distribution for the 80 mm thick steel mat.

3. Conclusion

In summary, the analysis of high-density polyethylene (HDPE) mats of varying thicknesses using beam-on-elastic-foundation analysis has provided insightful results regarding shear, moment, and bearing pressure distributions. The findings indicate that thicker HDPE mats contribute to reduced pressure at the centre, suggesting an advantage in terms of structural integrity. A comparative analysis of an 80 mm thick steel mat revealed that it exhibits significantly higher stiffness compared to the HDPE mats, leading to a more uniform pressure distribution. These results underscore the potential advantages of steel or aluminium mats in applications where enhanced stiffness and pressure uniformity are critical.

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