SECTION 6

Pavement Analysis

TMS Consultants • Lonco Inc.
Hook Engineering • Dr. George Hearn

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Task 6 - Pavement Impacts

This portion of the study will evaluate the impacts to the pavement subsection of the transportation system due to increased weights of nondivisible loads. The base vehicle for comparison is a loaded vehicle with only one panel. All base vehicles are assumed to be within the legal load limits of 70 to 80 thousand pounds. This represents one panel being hauled individually. The configuration of the trailer would change in order to more safely carry one panel. However there is no indication that the axle configurations would be modified.

Methodology

In order to evaluate the impacts of the loads, a mechanistic approach to the analysis was chosen. This is consistent with the move through out the world for a more predictable and rational method of pavement design. The new AASHTO pavement design procedures, due out in several years will incorporate a mechanistic design procedure. Several programs were evaluated for use in the analysis. After considerable study and evaluation, ELSYM5 was chosen for flexible and composite pavements, and KENSLABS was chosen for rigid pavement analysis.

Both programs allow for loads and wheel configurations to be varied, along with several variables for pavement materials. Both programs allow the user to look at stresses and strains at various locations from the load, in all three axis, x, y and z. Both programs are DOS based, and generally compare very well with the other design methods available.

ELSYM5

This programs allows for the analysis of an entire tractor trailer combination at one time. It allows for the analysis to be performed at up to 10 locations in the x and y direction, and up to 10 locations in the z direction for each individual x y pair. For purposes of the analysis, 0 in the x direction was assumed to be directly under the front or steering axle of the power unit. Analysis was then performed along the axle. It was found that the maximum impacts occurred directly between the two wheel locations. This design point was then utilized, and analysis made at one foot increments from the front of the trailer to the rear of the trailer.

An analysis was made on three separate pavement types, 12" full depth asphalt, 6" of asphalt on 12" of aggregate base course, and 4" of asphalt on 8" concrete pavement. These pavement types were chosen because they represent the types of pavements typically encountered by the trucks carrying the nondivisible loads studied by this report and the Request For Proposal (RFP) specified that these pavement types be analyzed. The design points were chosen at the bottom of each layer, including the top of the subgrade. The design analysis is attached in appendices 6E-a, b and c respectively.

The principal stresses at a specific distance from the drive axle were plotted for each separate pavement type. These graphs show that the stresses increase as the loads increase and the point of maximum stress for any weighted load is underneath the drive axles. These graphs are shown as appendices 6A-1 through 6A-5. The principal strains at a specific distance from the drive axle were also plotted for each separate pavement type. These graphs show that the strains increase as the loads increase and the point of maximum strain for any weighted load is underneath the drive axles. These graphs are shown as appendices 6A-6 through 6A-8.

The strains resulting from one extra weight load were compared to the strains from two legal limit divisible loads added together for each separate pavement type. The rationale being that if the nondivisible exemption did not exist, two legal limit loads would be needed to transport the same prestress concrete panels. The results from this analysis are shown as Appendix 6B-1. It can be seen from the charts that two divisible loads result in higher strains than one non-divisible load for the same total weight. It can also be seen from the chart that highest stains are seen in the six-inch asphalt on twelve aggregate base course. The next highest strains are seen in the twelve-inch asphalt, and the lowest strains are seen in the four inch asphalt on eight inches on concrete pavement.

KENSLABS

This program allows for the analysis of PCC "concrete" pavements at various joint spacing and thickness. An initial analysis was performed to find where the forces were most significant. It was determined that the load placed at the corner of a longitudinal and transverse joint provided the optimal design point for comparison purposes. The program inputs are slightly different from ELSYM5. Because of the typical joint spacings in Colorado, and the size of the design vehicles, each axle group was analyzed separately. Additionally, the loads are input as a function of tire area, by the x and y coordinates of each tires' footprint. Both 8" and 12" concrete pavements were analyzed. This data is presented in appendices 6E-d, and 6E-e respectively.

FATIGUE ANALYSIS

The fatigue ratios and deformation ratios resulting from one extra weight load were compared to the fatigue ratios and deformation ratios from two legal limit divisible loads added together for each separate pavement type. The rationale being that if the nondivisible exemption did not exist, two legal limit loads would be needed to transport the same prestress concrete panels. Fatigue ratios and deformations ratios were derived from Asphalt Institute fatigue and deformation formulae and Asphalt Institute and Shell fatigue and deformation factors were applied in the calculations. These ratios are presented in Table 6-1, Fatigue and Deformation Ratios and the results from this analysis are shown graphically as Appendix 6C and 6D.

Table 6-1 Fatigue and Deformation Ratios

Asphalt Institute Fatigue Cracking f2=3.291

	20k	25k	30k	35k
6 0n 12 Div. Loads	6.00	7.65	9.59	11.47
6 0n 12 Non-Div. Loads	6.79	9.30	13.06	18.32
12 in HBP Div. Loads	6.00	7.59	9.43	11.18
12 in HBP Non-Div. Loads	6.57	8.87	12.28	15.58
4 on 8 Div. Loads	6.00	7.54	9.32	10.97
4 on 8 Non-Div. Loads	6.41	8.57	11.75	14.70
8 in PCCP Div. Loads	6.00	7.32	8.82	10.47
8 in PCCP Non-Div. Loads	6.15	8.26	10.85	8.00
12 in PCCP Div. Loads	6.00	7.37	8.93	10.67
12 in PCCP Non-Div. Loads	6.31	8.58	11.40	10.54

Shell Fatigue Cracking f2=5.671

	20k	25k	30k	35k
6 0n 12 Div. Loads	6.00	9.12	13.47	18.32
6 0n 12 Non-Div. Loads	12.26	21.08	37.86	88.69
12 in HBP Div. Loads	6.00	8.99	13.07	17.53
12 in HBP Non-Div. Loads	11.59	19.43	34.08	63.38
4 on 8 Div. Loads	6.00	8.89	12.81	16.97
4 on 8 Non-Div. Loads	11.10	18.33	31.54	56.89
8 in PCCP Div. Loads	6.00	7.32	8.82	10.47
8 in PCCP Non-Div. Loads	6.15	8.26	10.85	8.00
12 in PCCP Div. Loads	6.00	7.37	8.93	10.67
12 in PCCP Non-Div. Loads	6.31	8.58	11.40	10.54

Asphalt Institute Permanent Deformation f2=4.477

	20k	25k	30k	35k
6 0n 12 Div. Loads	6.00	8.35	11.36	14.48
6 0n 12 Non-Div. Loads	9.12	13.98	22.20	39.30
12 in HBP Div. Loads	6.00	8.26	11.09	13.99
12 in HBP Non-Div. Loads	8.72	13.11	20.43	30.76
4 on 8 Div. Loads	6.00	8.18	10.92	13.63
4 on 8 Non-Div. Loads	8.42	12.52	19.22	28.31
8 in PCCP Div. Loads	6.00	7.32	8.82	10.47
8 in PCCP Non-Div. Loads	6.15	8.26	10.85	8.00
12 in PCCP Div. Loads	6.00	7.37	8.93	10.67
12 in PCCP Non-Div. Loads	6.31	8.58	11.40	10.54

Shell Permanent Deformation f2=4.0

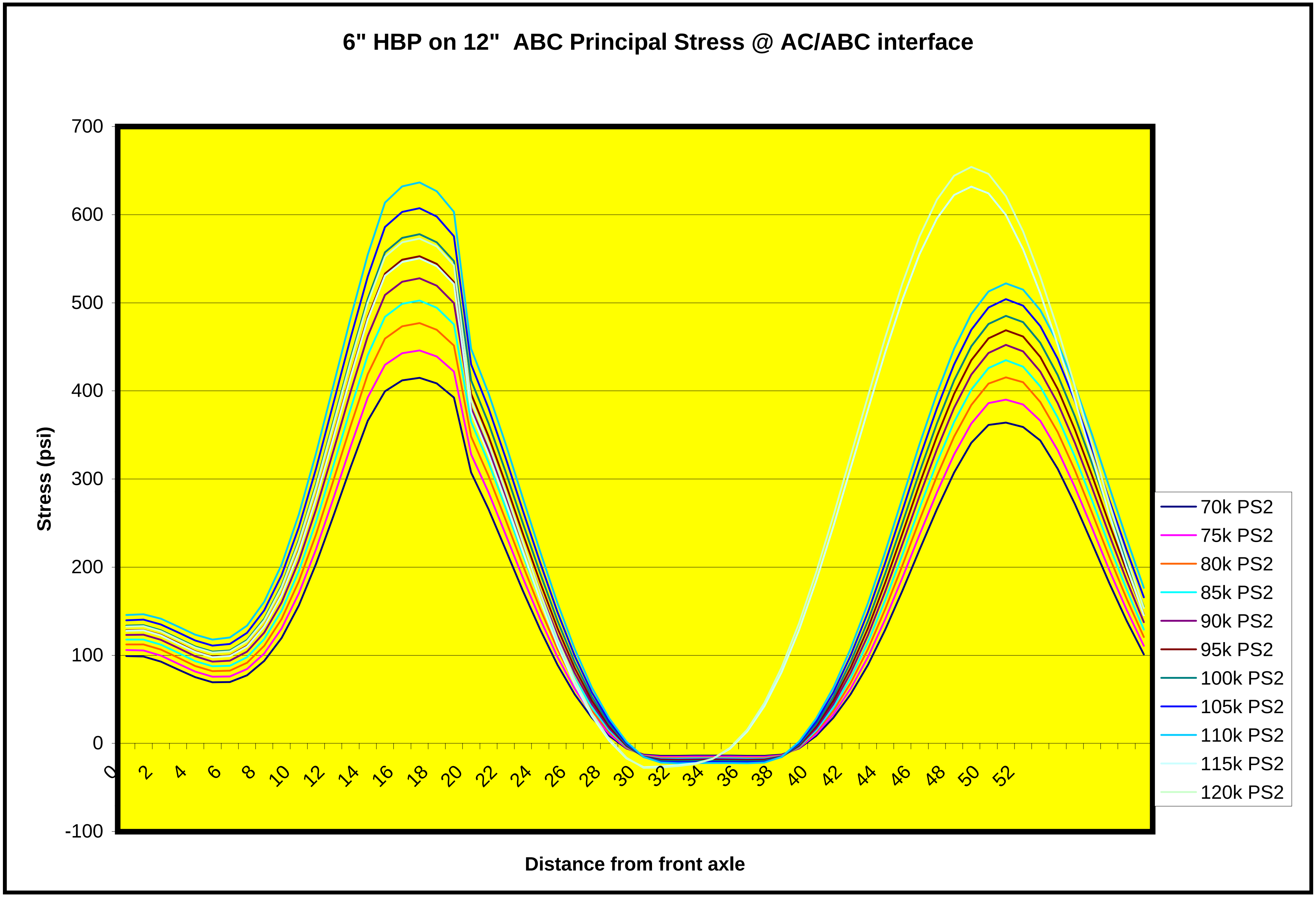
	20k	25k	30k	35k
6 0n 12 Div. Loads	6.00	8.06	10.61	13.18
6 0n 12 Non-Div. Loads	8.10	11.87	17.93	28.74
12 in HBP Div. Loads	6.00	7.98	10.39	12.78
12 in HBP Non-Div. Loads	7.78	11.20	16.65	23.28
4 on 8 Div. Loads	6.00	7.92	10.24	12.49
4 on 8 Non-Div. Loads	7.55	10.75	15.76	21.65
8 in PCCP Div. Loads	6.00	7.32	8.82	10.47
8 in PCCP Non-Div. Loads	6.15	8.26	10.85	8.00
12 in PCCP Div. Loads	6.00	7.37	8.93	10.67
12 in PCCP Non-Div. Loads	6.31	8.58	11.40	10.54

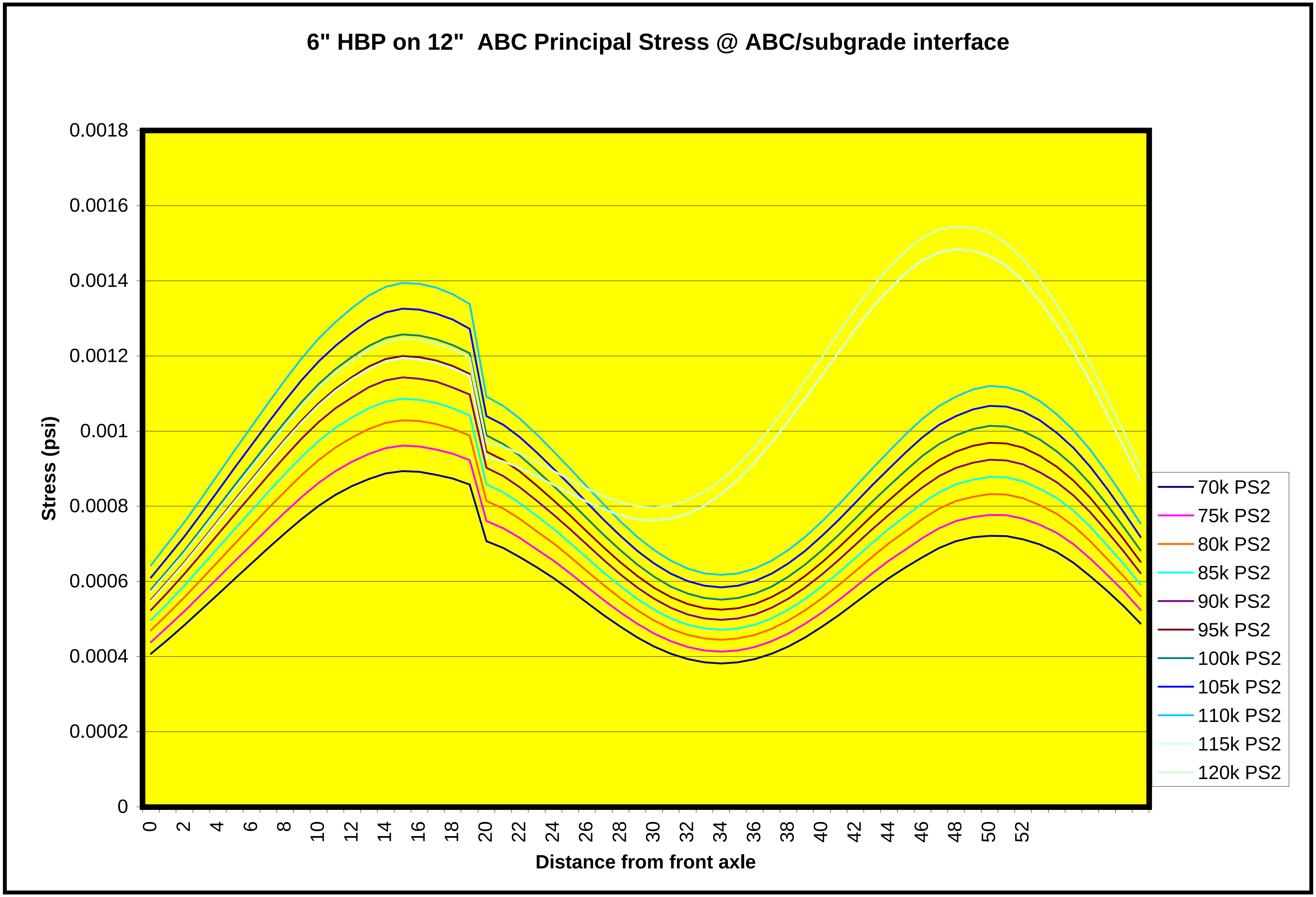
A comparison of different design parameters was then undertaken. For purposes of this report, fatigue was chosen as the comparison factor. Each load pair was analyzed and compared to the fatigue of its divisible load. This analysis was done for 70, 75, and 80 kip loads. These results are shown graphically as Appendices 6-C.

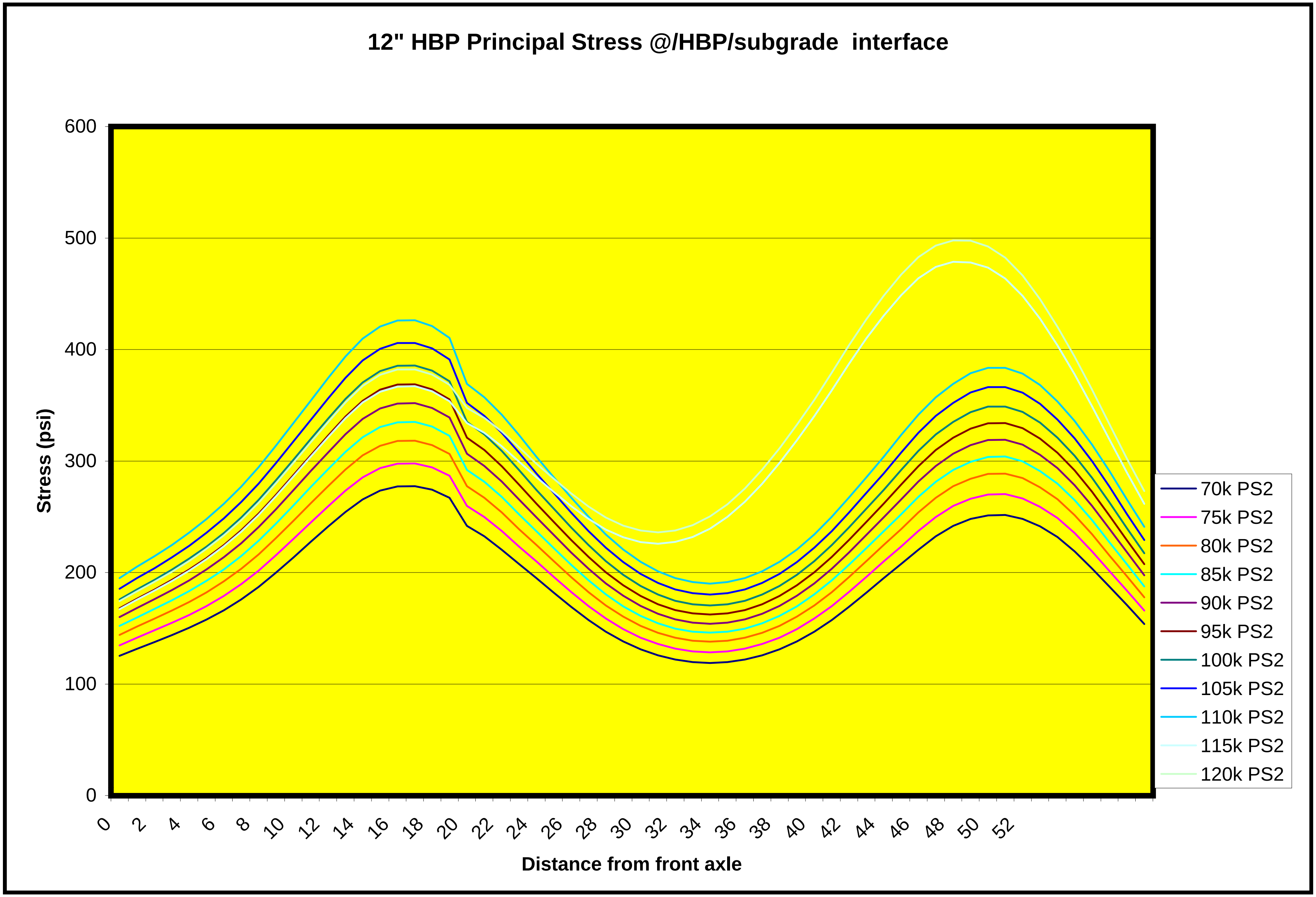
A model of the routes analyzed in Section 3 of the report was chosen, and the fatigue criteria is weighted based on this information. Over 90% of the loads are on the stronger sections, and their fatigue impacts are the lesser. Less then 10% of the vehicle miles traveled are on weaker pavements, where the fatigue differences are higher. These graphs are shown in the Appendices. As a result of the analysis, the pavement damage is slightly greater.

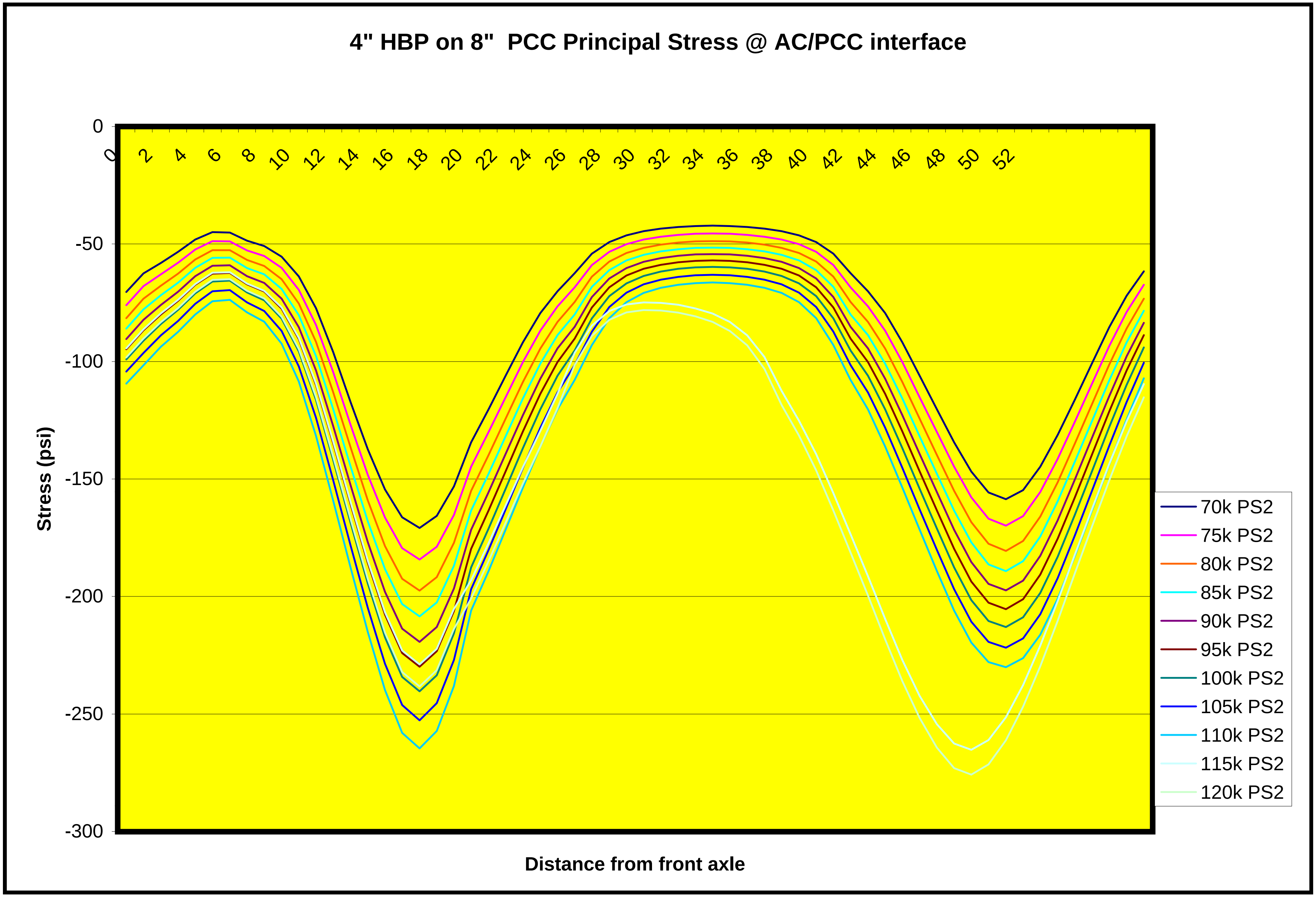
Because the expected total number of these types of loads is relatively small, these loads can be carried on the system, with little effect to the pavement system. It must be reiterated that these results are only for concrete precast wall panels manufactured at existing precast yards within Colorado. These results may not be extrapolated to other products, or other industries. It can be seen from the analysis, as an example, that the same exemption applied to agriculture would have more than 20% negative impact to the pavement systems on State Highways, with even greater impacts to off-system pavements. The uniqueness of the market, and the location of the manufacturing to serve this market, makes nondivisible precast panels unique in its pavement impacts.

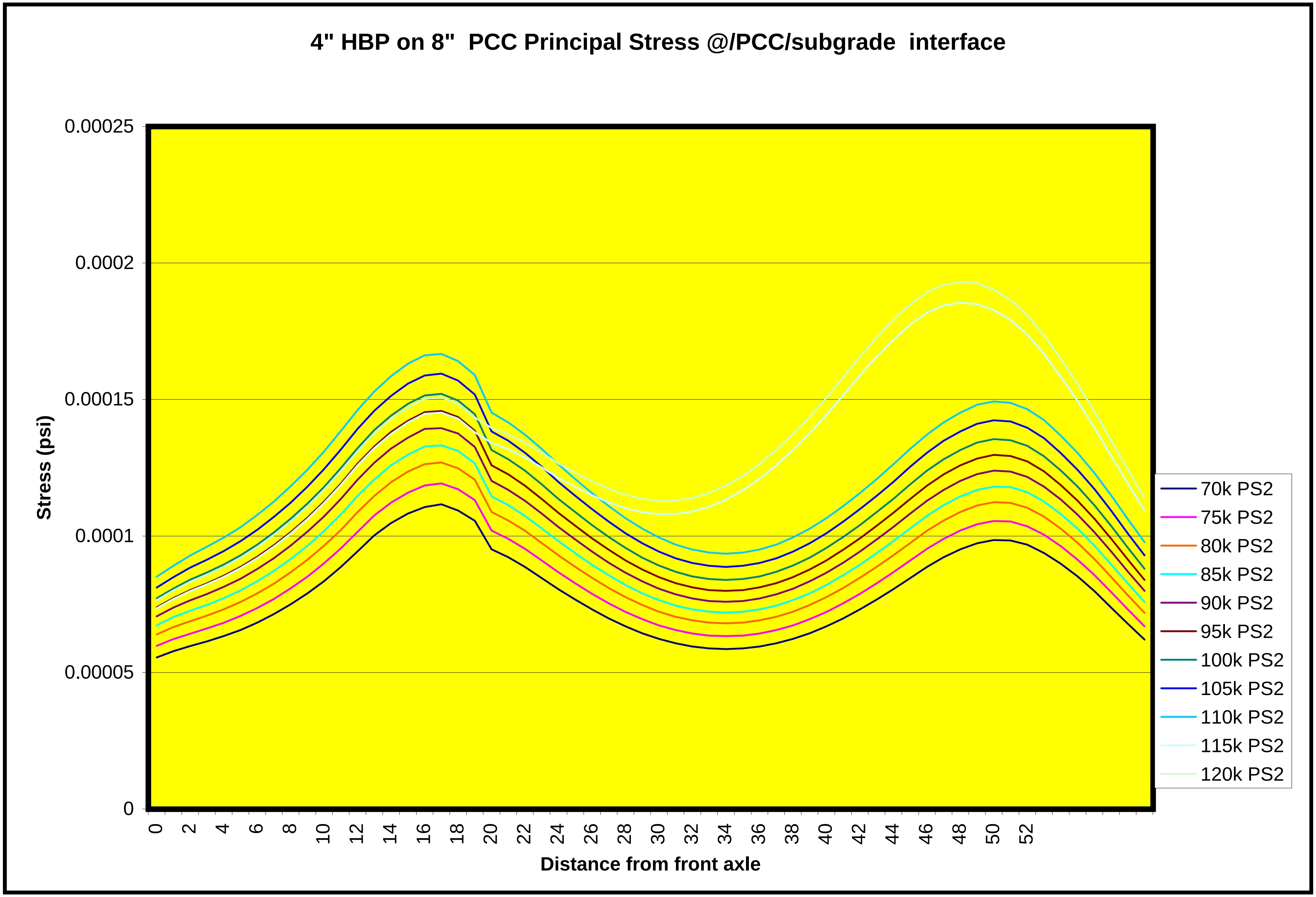
Should the loads increase due to different axle configurations of trailers, and different trailer loading techniques, the impacts could also increase to undesirable levels.

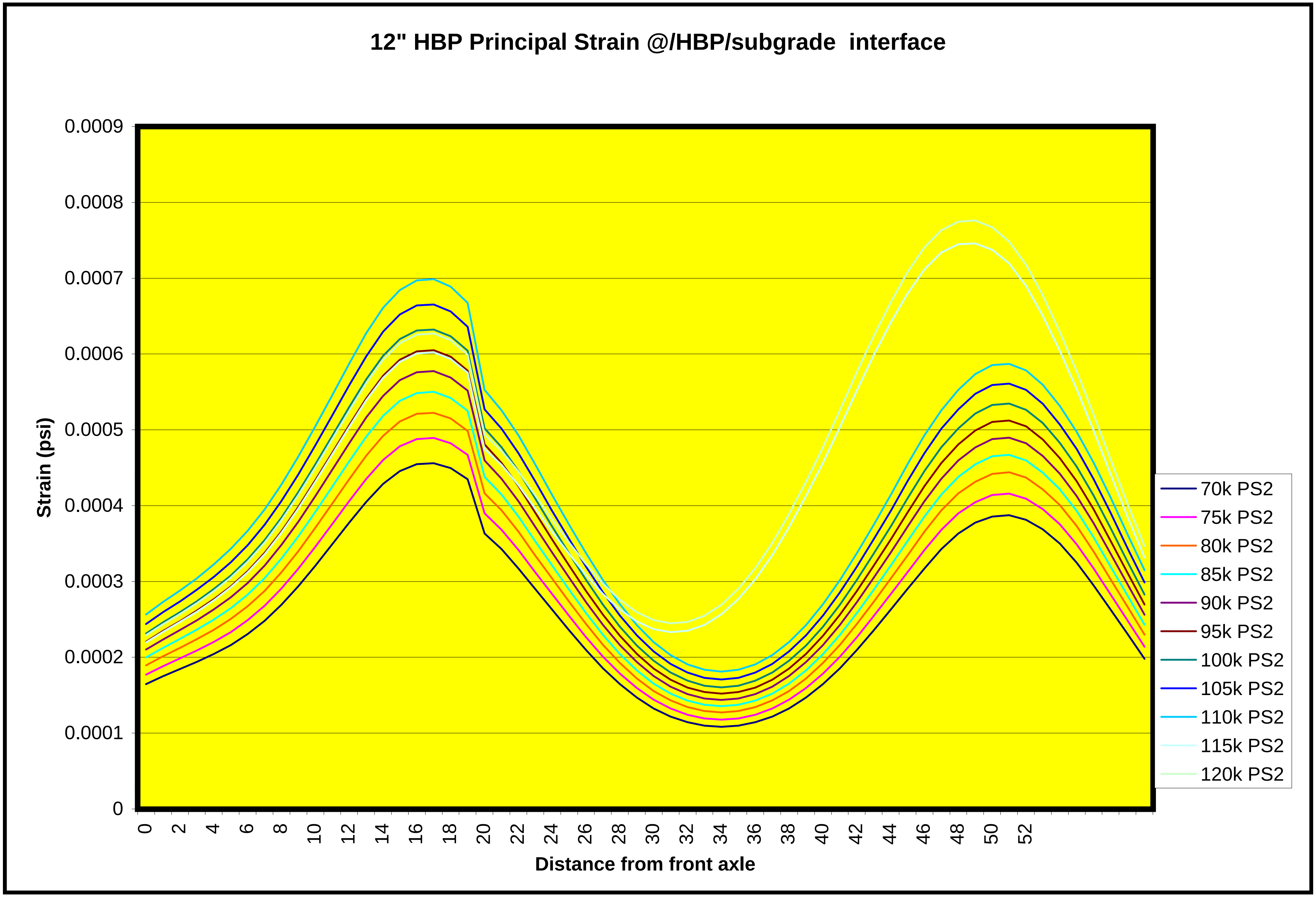

6" HBP on 12" ABC Principal Stress @ AC/ABC interface
Stress (psi)
700
600
500
400
300
200
100
0
-100
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2

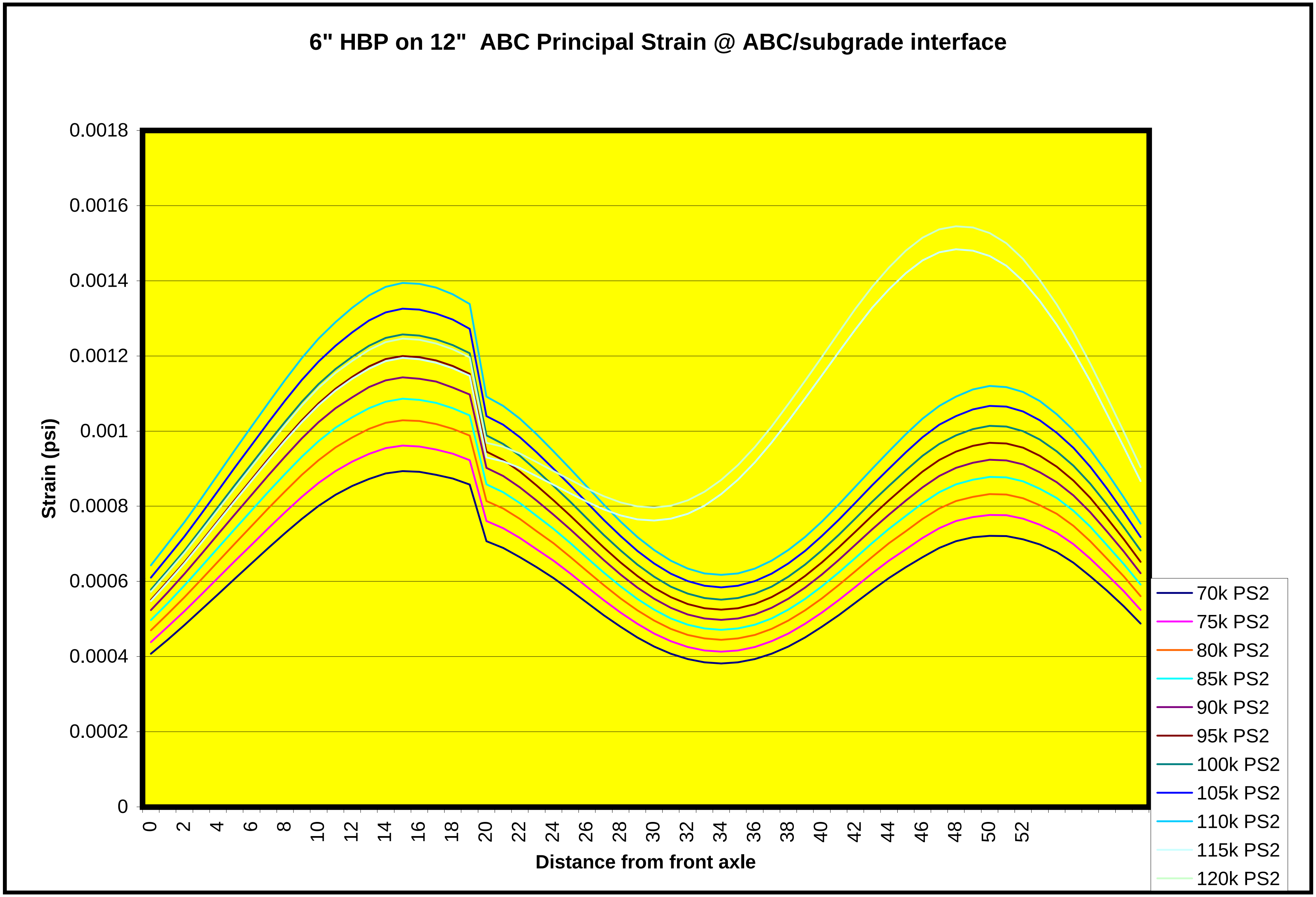

6" HBP on 12" ABC Principal Stress @ ABC/subgrade interface
Stress (psi)
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2

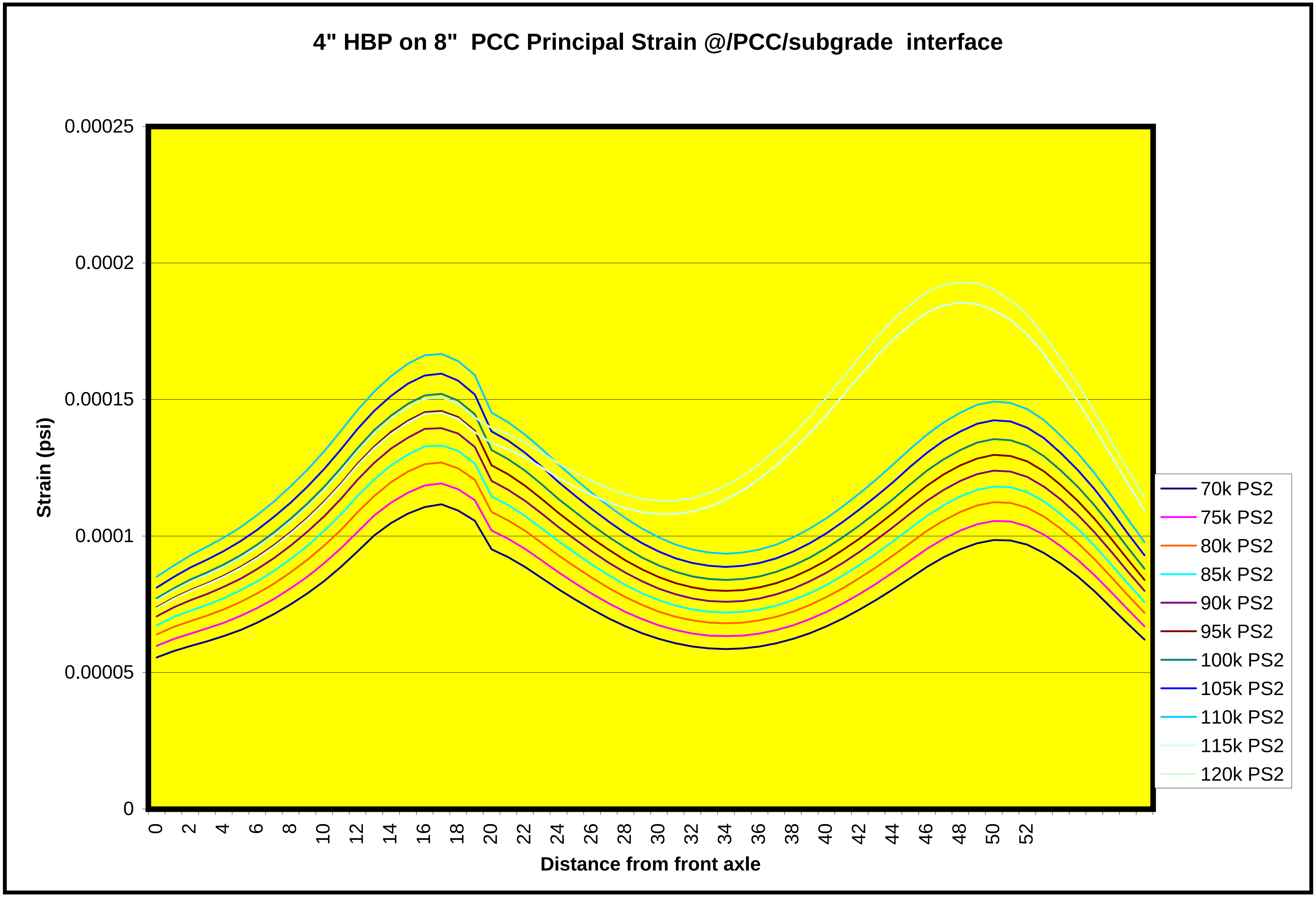

12" HBP Principal Stress @/HBP/subgrade interface
Stress (psi)
0
100
200
300
400
500
600
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2

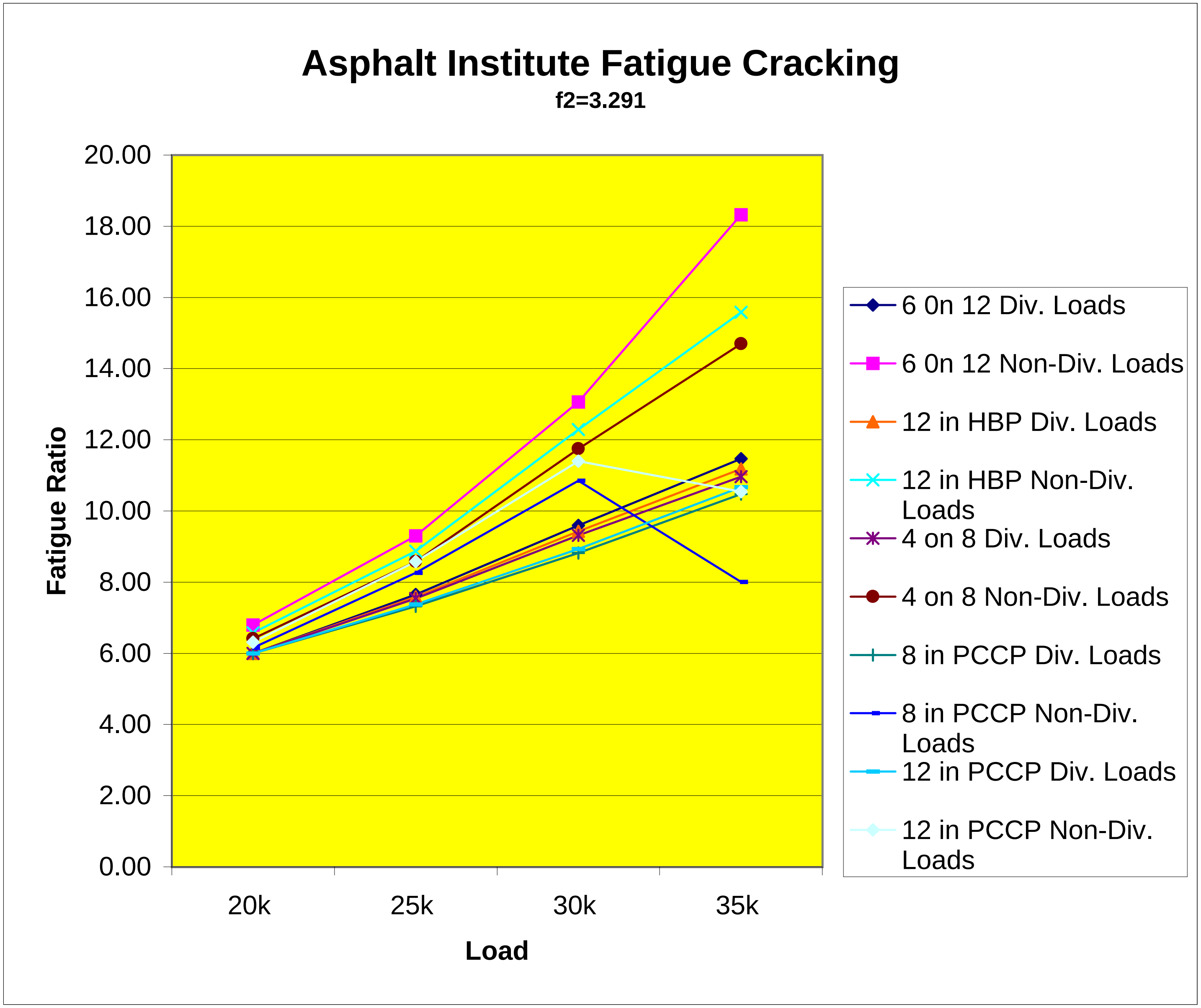

4" HBP on 8" PCC Principal Stress @ AC/PCC interface
0
-50
-100
-150
-200
-250
-300
Stress (psi)
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2

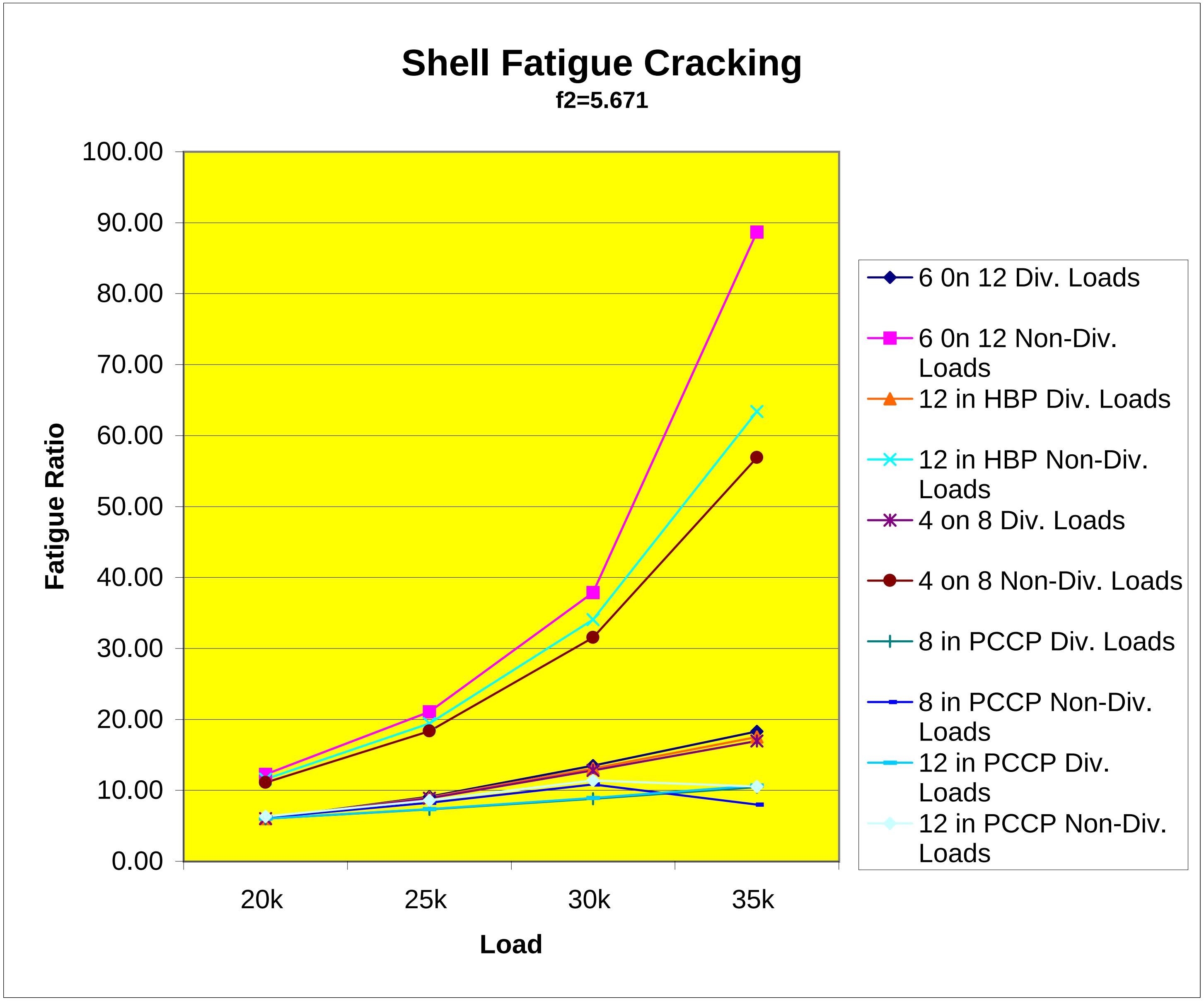

4" HBP on 8" PCC Principal Stress @/PCC/subgrade interface
Stress (psi)
0.00025
0.0002
0.00015
0.0001
0.00005
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2

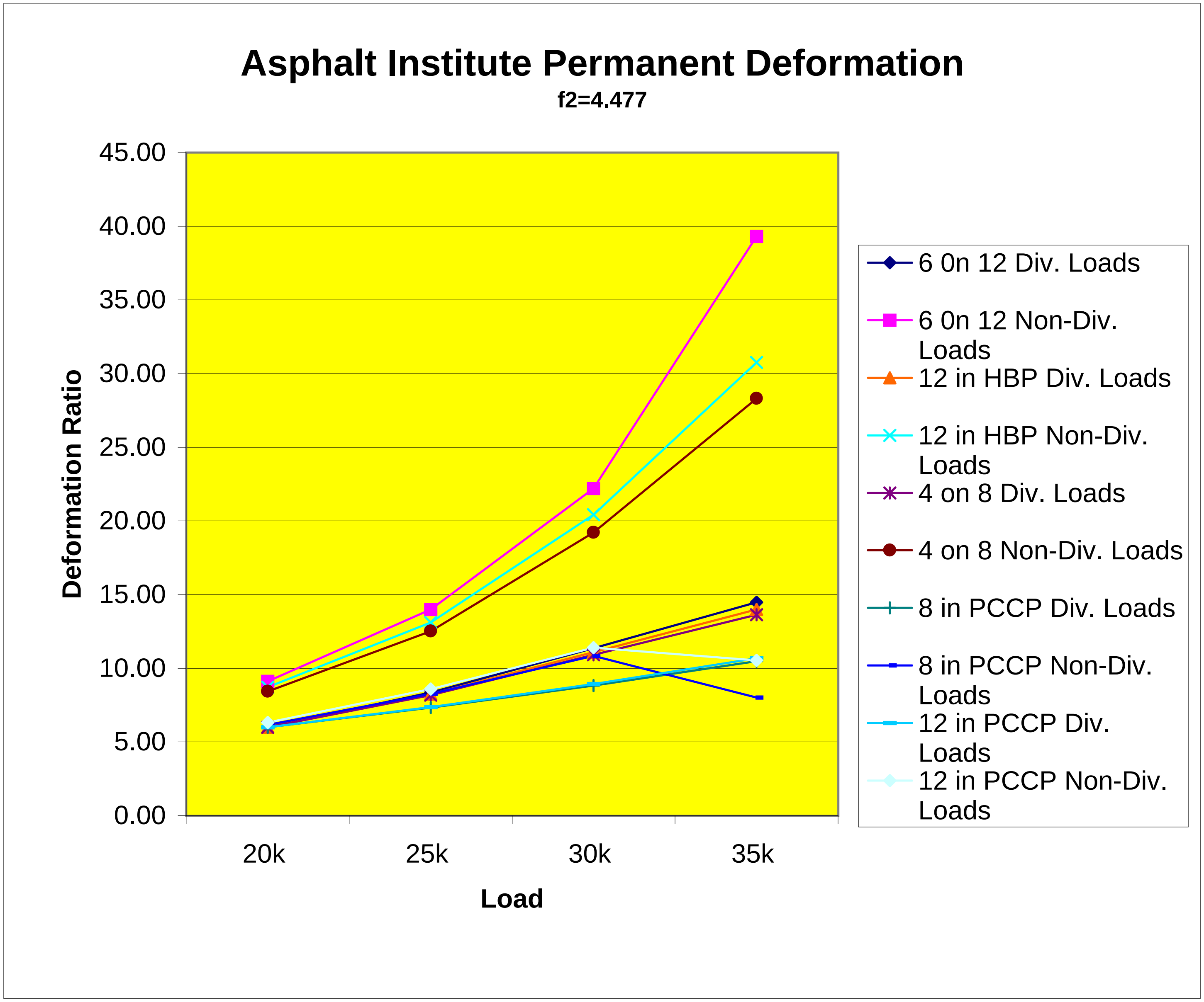

12" HBP Principal Strain @/HBP/subgrade interface
Strain (psi)
0.0009
0.0008
0.0007
0.0006
0.0005
0.0004
0.0003
0.0002
0.0001
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2

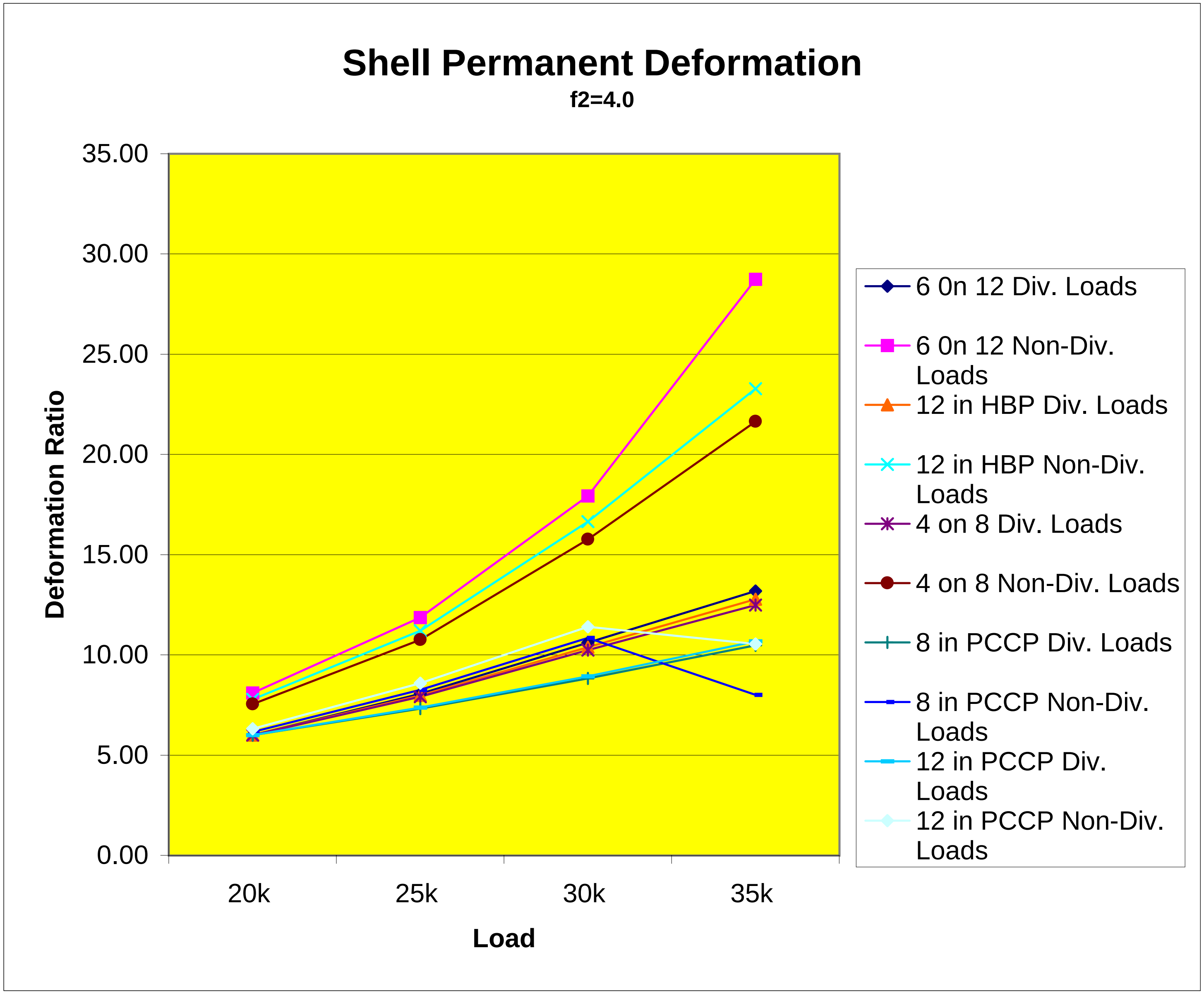

6" HBP on 12" ABC Principal Strain @ ABC/subgrade interface
Strain (psi)
0.0018
0.0016
0.0014
0.0012
0.001
0.0008
0.0006
0.0004
0.0002
0
0 2 4 6 8 10 12 14 16 18 20 22 24 26 28 30 32 34 36 38 40 42 44 46 48 50 52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2

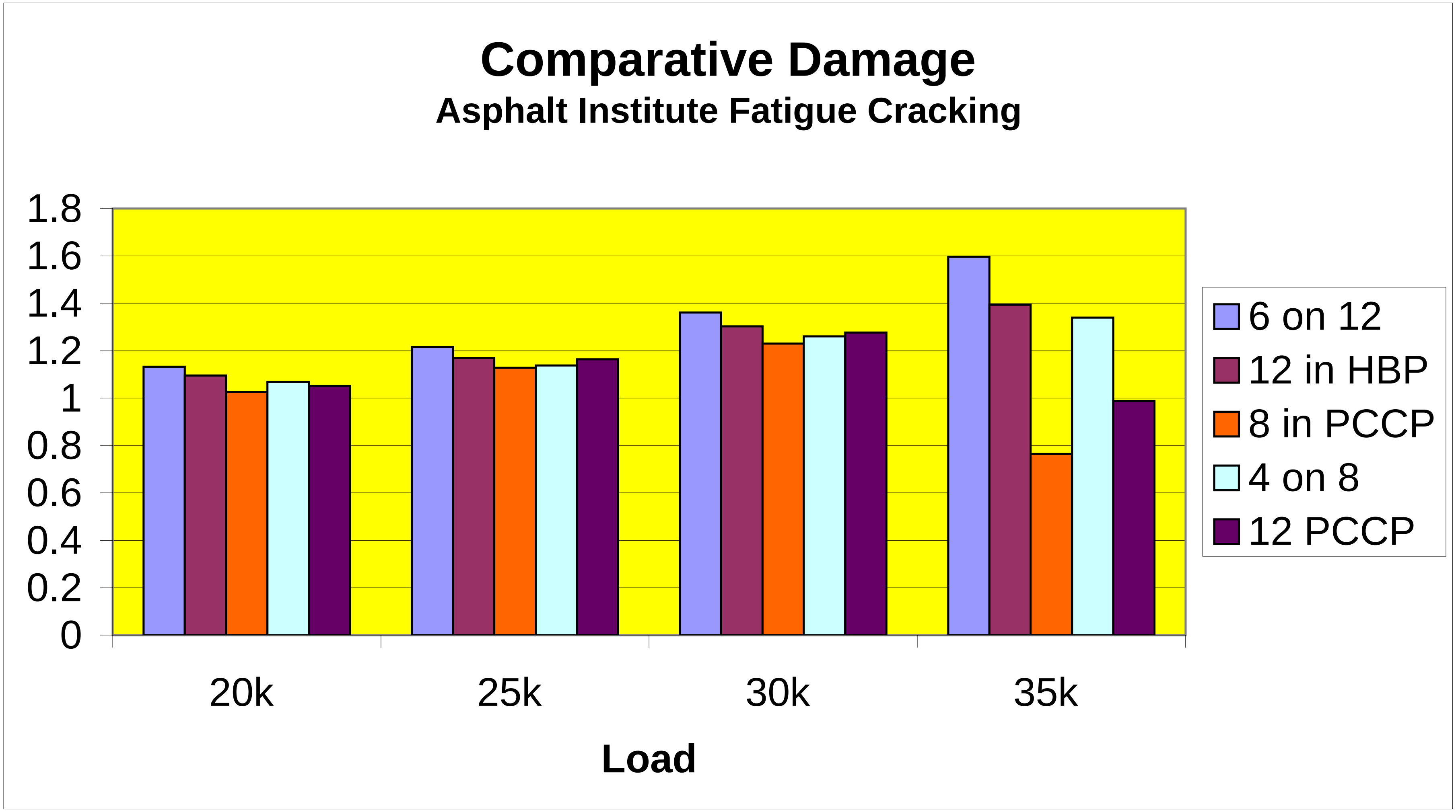

4" HBP on 8" PCC Principal Strain @/PCC/subgrade interface
Strain (psi)
0.00025
0.0002
0.00015
0.0001
0.00005
0
0
2
4
6
8
10
12
14
16
18
20
22
24
26
28
30
32
34
36
38
40
42
44
46
48
50
52
Distance from front axle
70k PS2
75k PS2
80k PS2
85k PS2
90k PS2
95k PS2
100k PS2
105k PS2
110k PS2
115k PS2
120k PS2


Asphalt Institute Fatigue Cracking
f2=3.291
Fatigue Ratio
20.00
18.00
16.00
14.00
12.00
10.00
8.00
6.00
4.00
2.00
0.00
20k
25k
30k
35k
Load
6 0n 12 Div. Loads
6 0n 12 Non-Div. Loads
12 in HBP Div. Loads
12 in HBP Non-Div. Loads
4 on 8 Div. Loads
4 on 8 Non-Div. Loads
8 in PCCP Div. Loads
8 in PCCP Non-Div. Loads
12 in PCCP Div. Loads
12 in PCCP Non-Div. Loads


Shell Fatigue Cracking
f2=5.671
Fatigue Ratio
100.00
90.00
80.00
70.00
60.00
50.00
40.00
30.00
20.00
10.00
0.00
20k
25k
30k
35k
Load
6 0n 12 Div. Loads
6 0n 12 Non-Div. Loads
12 in HBP Div. Loads
12 in HBP Non-Div. Loads
4 on 8 Div. Loads
4 on 8 Non-Div. Loads
8 in PCCP Div. Loads
8 in PCCP Non-Div. Loads
12 in PCCP Div. Loads
12 in PCCP Non-Div. Loads


Asphalt Institute Permanent Deformation
f2=4.477
Deformation Ratio
45.00
40.00
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
20k
25k
30k
35k
Load
6 0n 12 Div. Loads
6 0n 12 Non-Div. Loads
12 in HBP Div. Loads
12 in HBP Non-Div. Loads
4 on 8 Div. Loads
4 on 8 Non-Div. Loads
8 in PCCP Div. Loads
8 in PCCP Non-Div. Loads
12 in PCCP Div. Loads
12 in PCCP Non-Div. Loads


Shell Permanent Deformation
f2=4.0
35.00
30.00
25.00
20.00
15.00
10.00
5.00
0.00
Deformation Ratio
20k
25k
30k
35k
Load
6 0n 12 Div. Loads
6 0n 12 Non-Div. Loads
12 in HBP Div. Loads
12 in HBP Non-Div. Loads
4 on 8 Div. Loads
4 on 8 Non-Div. Loads
8 in PCCP Div. Loads
8 in PCCP Non-Div. Loads
12 in PCCP Div. Loads
12 in PCCP Non-Div. Loads


Comparative Damage
Asphalt Institute Fatigue Cracking
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
20k
25k
30k
35k
Load
6 on 12
12 in HBP
8 in PCCP
4 on 8
12 PCCP