HITACHI

GE Hitachi Nuclear Energy

Richard E. Kingston
Vice President, ESBWR Licensing

P.O. Box 780
3901 Castle Hayne Road, M/C A-55
Wilmington, NC 28402 USA

T 910.675.6192
F 910.362.6192
rick.kingston@ge.com

MFN 06-407
Supplement 9

Docket No. 52-010

July 30, 2008

U.S. Nuclear Regulatory Commission
Document Control Desk
Washington, D.C. 20555-0001

Subject: Response to Portion of NRC RAI Letter No. 166 Related to ESBWR Design Certification Application DCD Tier 2 Section 3.8 Seismic Category I Structures RAI Number 3.8-93 S03

The purpose of this letter is to submit the GE Hitachi Nuclear Energy (GEH) response to the U.S. Nuclear Regulatory Commission (NRC) Request for Additional Information (RAI) received from the NRC via Reference 1 (RAI 3.8-93 S03).

Enclosure 1 contains the GEH response to NRC RAI 3.8-93 S03 that was received from the NRC with NRC RAI Letter Number 166 on March 28, 2008 (Reference 1). The original RAI and previous supplements from the NRC and GEH responses are listed in References 2 through 5.

If you have any questions or require additional information, please contact me.

Sincerely,

Richard E. Kingston

Richard E. Kingston
Vice President, ESBWR Licensing

D068
NRO

References:

1. MFN 08-316, Letter from U.S. Nuclear Regulatory Commission to Robert E. Brown, *Request for Additional Information Letter No. 166 Related to ESBWR Design Certification Application*, March 28, 2008

2. MFN 06-407, Supplement 3, Letter from James C. Kinsey, GEH to U.S. Nuclear Regulatory Commission, *Response to Portion of NRC Request for Additional Information Letter No. 38 Related to ESBWR Design Certification Application – DCD Tier 2 Section 3.8 – Seismic Category I Structures - RAI Numbers 3.8-28 S02, 3.8-76 S02, 3.8-93 S02, 3.8-94 S02, 3.8-96 S02, 3.8-101 S02, 3.8-102 S02 and 3.8-103 S02*, November 28, 2007

3. MFN 06-407, Supplement 2, Letter from James C. Kinsey to U.S. Nuclear Regulatory Commission, *Response to Portion of NRC Request for Additional Information Letter No. 38 Related to ESBWR Design Certification Application –Structural Analysis – RAI Numbers 3.8-81 S01, 3.8-85 S01, 3.8-86 S01, 3.8-88 S01, 3.8-92 S01, 3.8-92 S01, 3.8-93 S01, 3.8-94 S01, 3.8-96 S01 and 3.8-99 S01*, dated March 26, 2007

4. MFN 06-407, Letter from David H. Hinds to U.S. Nuclear Regulatory Commission, *Response to Portion of NRC Request for Additional Information Letter No. 38 Related to ESBWR Design Certification Application –Structural Analysis – RAI Numbers 3.8-17, 3.8-24, 3.8-28, 3.8-32, 3.8-33 through 3.8-38, 3.8-44, 3.8-59, 3.8-62, 3.8-65, 3.8-69, 3.8-73, 3.8-76, 3.8-77, 3.8-79, 3.8-80, 3.8-81, 3.8-84, 3.8-85, 3.8-86, 3.8-88, 3.8-89, 3.8-92, 3.8-93 through 3.8-97, 3.8-99, 3.8-101, 3.8-102 and 3.8-103*, dated November 8, 2006

5. MFN 06-197, Letter from U.S. Nuclear Regulatory Commission to David H. Hinds, *Request for Additional Information Letter No. 38 Related to ESBWR Design Certification Application*, June 23, 2006

Enclosure:

1 Response to Portion of NRC RAI Letter No. 166 Related to ESBWR Design Certification Application - DCD Tier 2 Section 3.8 – Seismic Category I Structures - RAI Numbers 3.8-93 S03

cc:	AE Cubbage	USNRC (with enclosures)
	RE Brown	GEH/Wilmington (with enclosures)
	DH Hinds	GEH/Wilmington (with enclosures)
	eDRF	0000-0084-3378 (RAI 3.8-93 S03)

ENCLOSURE 1

MFN 06-407, Supplement 9

Response to Portion of NRC RAI Letter No. 166 Related to ESBWR Design Certification Application

DCD Tier 2 Section 3.8 – Seismic Category I Structures

RAI Number 3.8-93 S03

For historical purposes, the original text of RAI 3.8-93 S03 and the GE responses are included. The attachments (if any) are not included from the original response(s) to avoid confusion.

NRC RAI 3.8-93

Section 3.8.5.4 states that total and differential settlements of the foundations must be considered, but refers to Section 3.8.6.2 for COL information. The DCD needs to clarify how settlement issues are incorporated into the generic design of the standard plant, and identify limitations on the magnitude of settlements, so that the COL applicant can ensure compliance with the standard design. Define the COL applicant actions required to confirm that the predicted site-specific settlement meets the standard plant design assumptions.

Include this information in the DCD. In addition, (1) identify the applicable detailed report/calculation (number, title, revision and date, and brief description of content) that will be available for audit by the staff, and (2) reference this report/calculation in the DCD.

GE Response

This response is similar to NRC RAI 3.8-92. The stipulated settlements will be incorporated into the total plant design as a requirement. The following evaluation, *Settlement Effect on Basemat Design*, clarifies the settlement issues. The COL holder will have to demonstrate that differential settlements at the site do not exceed this value by instituting a settlement monitoring program or justify in the COL why it would not be necessary.

The confirmation for settlement effect on basemat design is provided by parametric analysis considering a variety of soil conditions and construction sequences as shown in the following evaluation, *Settlement Effect on Basemat Design*. As a result, the basemat stresses reported in the DCD are not affected by horizontal variations in spring stiffness. Also basemat stresses during construction are much smaller than DCD design stresses.

No DCD change will be made in response to this RAI.

Settlement Effect on Basemat Design

1. Scope

Additional topics discussed at audit have been stated in response to NRC RAIs 3.8-13 and 92 regarding the ESBWR basemat design. Additionally NRC recommended that to refer DCD of AP600 including the discussion during construction period. The main purpose of these requests is to estimate the differential settlement effect on basemat design during Operation and Construction Phase respectively. The discussion was stated in response to NRC RAI 3.8-93.

This section provides the result of the estimation concerning following items with the FEM model.

- Non-uniform soil condition under basemat during normal operation
- Settlement effect on basemat during construction period

2. Normal Operation Phase

Analyses are performed under the variety of soil condition (non-uniform condition), and then they are compared to the DCD design. The analytical conditions are as follows:

- FEM Model : Global FEM Model (DCD Design Model)
- Soil Condition : "Hard Spot", stiff spring under the Pedestal area.
  Three types of soil conditions are considered as "Hard Spot" as shown in Figure 3.8-93(1).
- Load : Dead Load

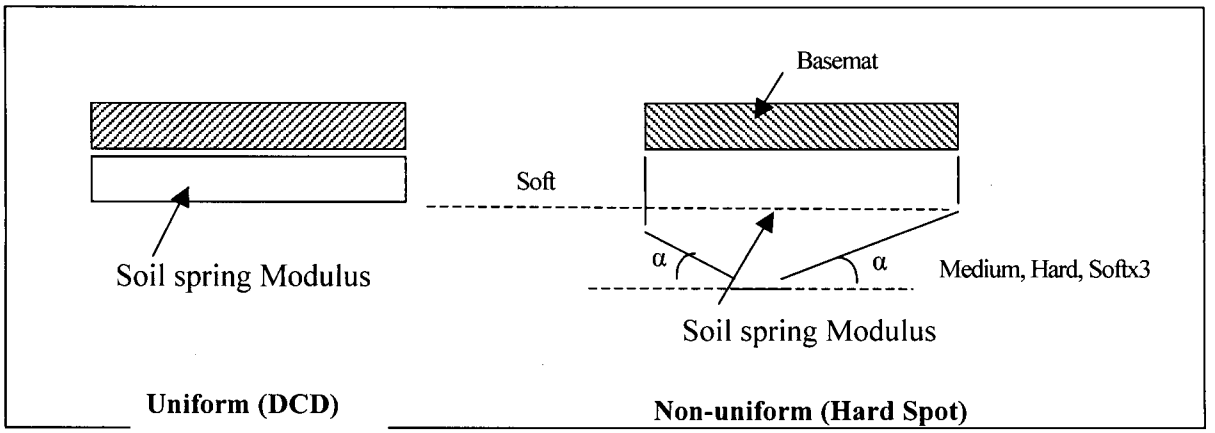


Figure 3.8-93(1) Soil conditions

Figure 3.8-93 (2) and (3) show the basemat deformation and bending moment of basemat comparing with those of DCD design (uniform soil condition). These indicate the bending moment of DCD design is larger or similar to Hard Spot condition since the soil springs are stiffer than DCD condition (uniform soft soil). Therefore there is no concern about basemat design if the building is settled on Hard Spot soil conditions.

3. Construction Phase

After the completion of basemat several part of building will be constructed based on planned construction sequence. This analytical study is provided to confirm the stress of basemat in construction period. Assumed sequence is as follows, but this is imaginary since these portions are constructed in short time periods:

Case A: sequentially outward construction

1. Pedestal poured up to 5m (below the floor EL-6400, approximately)
2. Apply loads by RCCV and B3F structure

3. Add exterior walls in RB
4. Add walls in FB area

Case B: Sequentially inward construction

Constructed into inverse direction of Case A.

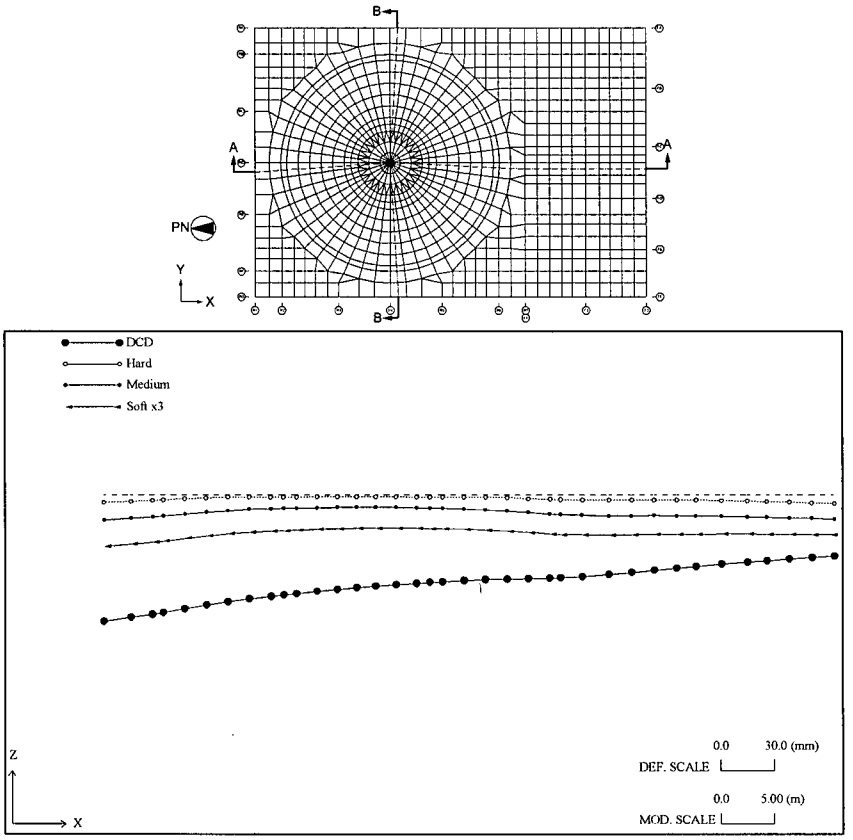
1. FB area poured (below the floor EL-6400, approximately)
2. Add exterior walls in RB
3. Add RCCV and B3F structure
4. Add pedestal

The analytical model has been extracted from global FEM model used for DCD design. Some modification has been applied to this as shown in Figure 3.8-93(4). This model is similar to the "Modified Truncated Model" provided to the NRC for confirmatory analysis. The height of structural members is limited to 5m in every top portion of the model considering construction plan. Figure 3.8-93(4) shows sequence of Case A.

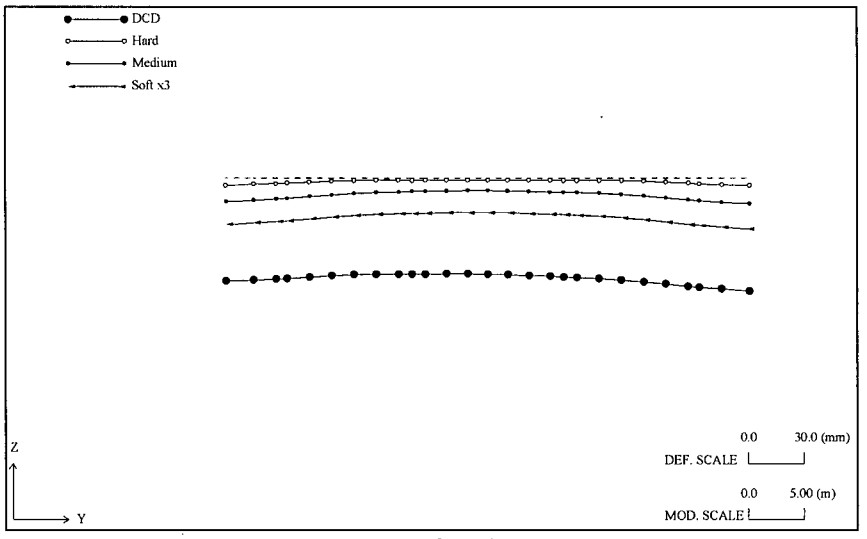
The dead loads are considered per element thickness and density of concrete which in the model. The analytical conditions are as follows:

- FEM Model : Based on the "Modified Truncated Model (a part of Global FEM Model).
- Soil Condition : "Uniform", soft soil spring under the basemat
- Load : Dead Load

Figures 3.8-93 (5) and (6) show deformation of basemat. The maximum settlement is 15 mm and the maximum differential settlement is 8 mm. Figures 3.8-93 (7) and (8) show bending moment of basemat comparing with those of DCD design (normal operation). These indicate the bending moment of DCD design is larger than the bending moment during the construction period.

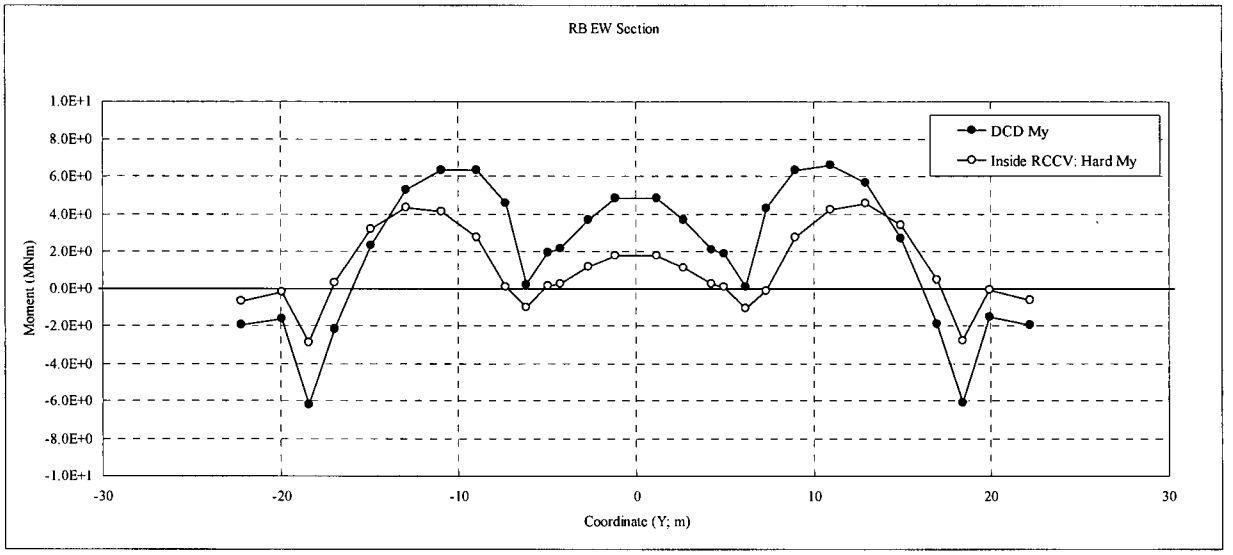


a) A-A Section

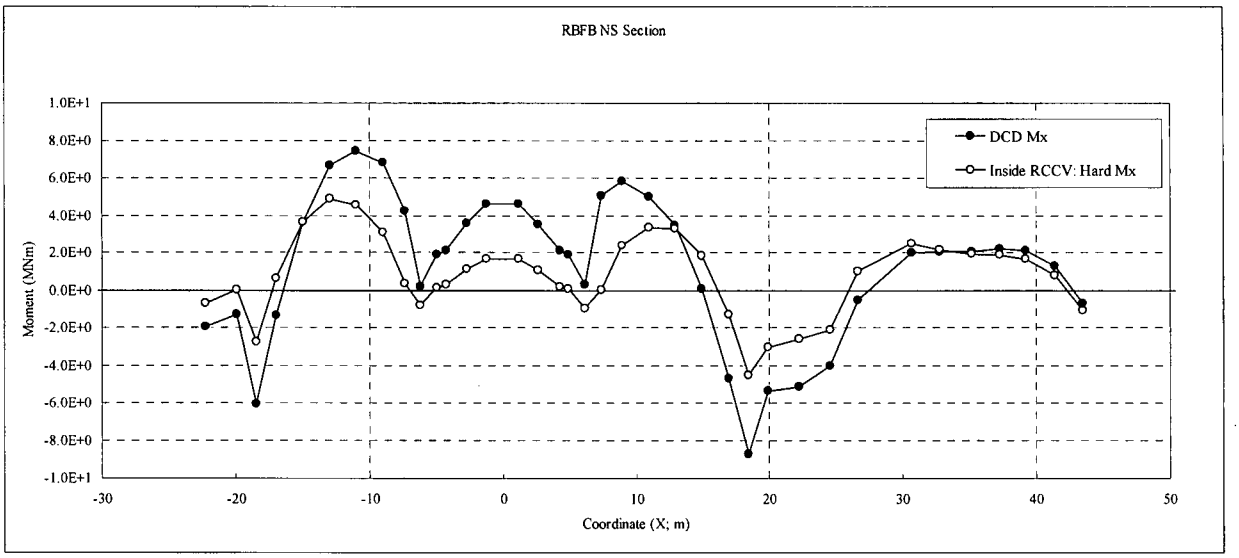


b) B-B Section

Figure 3.8-93(2) Comparison of Basemat Deformation



(a) My in B-B Section



(b) Mx in A-A Section

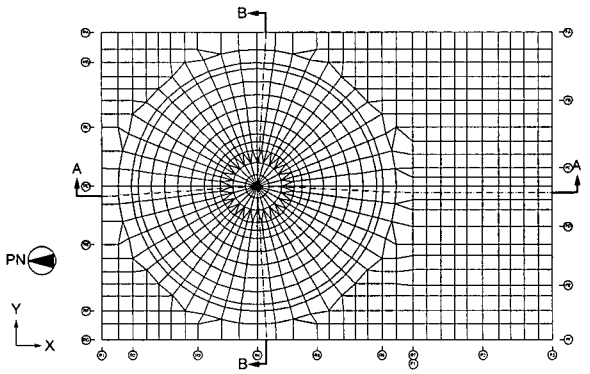
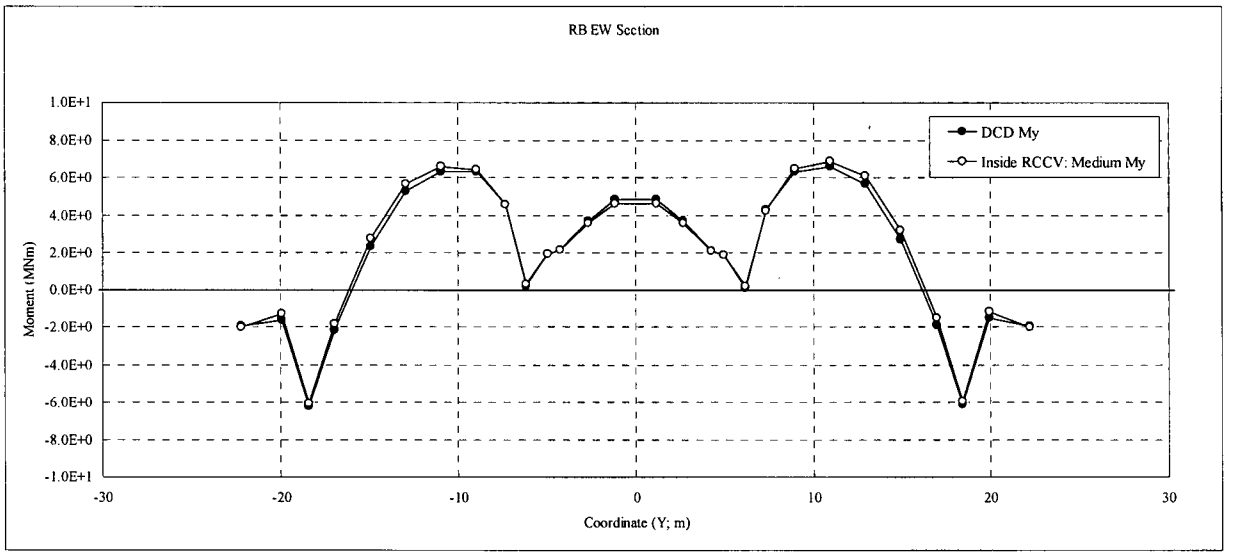
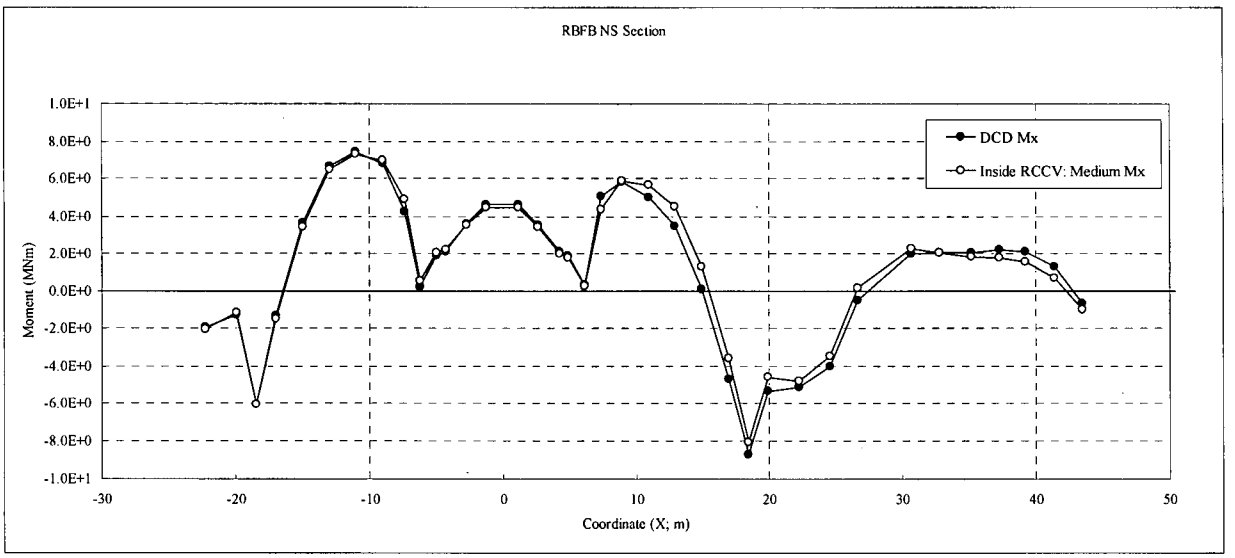


Figure 3.8-93(3)-a Comparison of Basemat Sectional Moments (Hard)



(a) My in B-B Section



(b) Mx in A-A Section

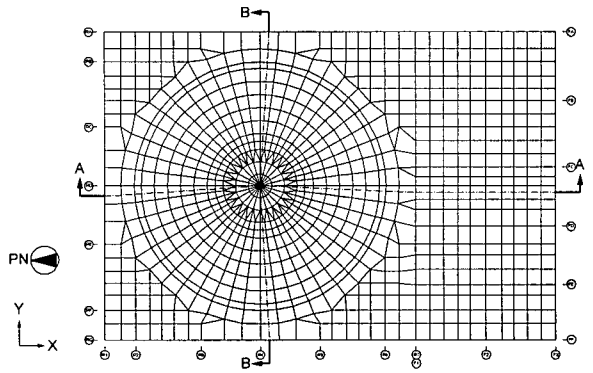
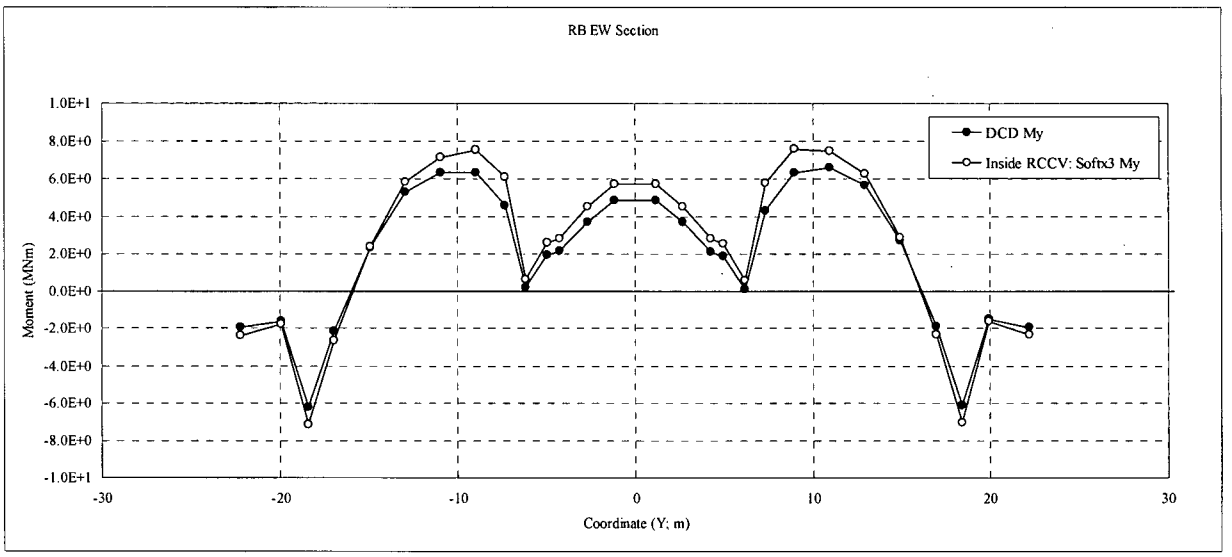
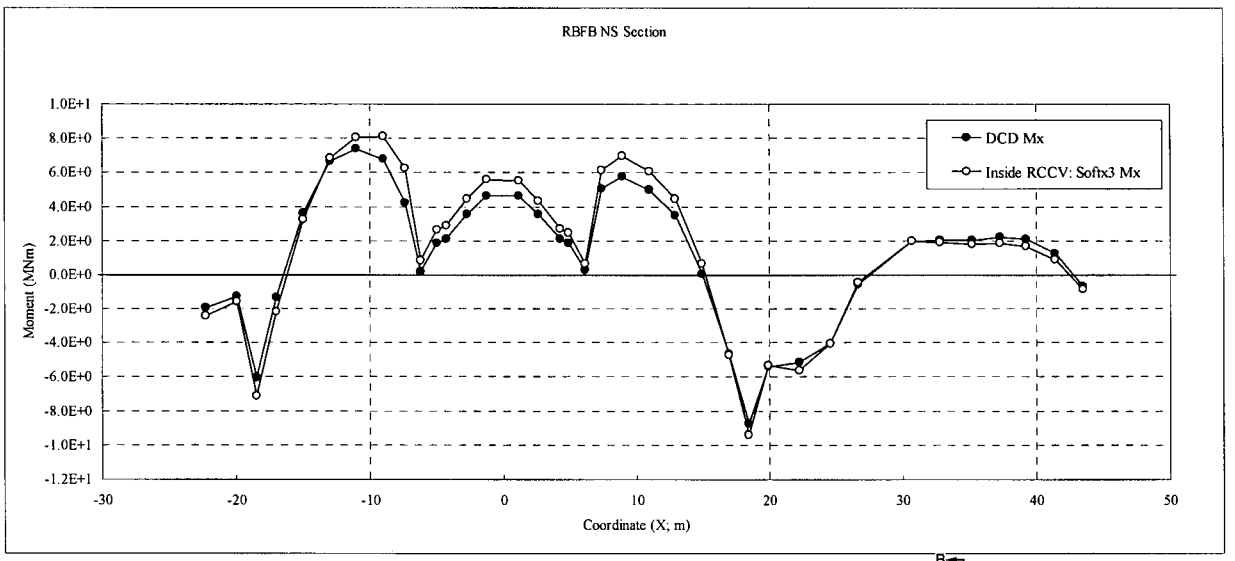


Figure 3.8-93(3)-b Comparison of Basemat Sectional Moments (Medium)



(a) My in B-B Section



(b) Mx in A-A Section

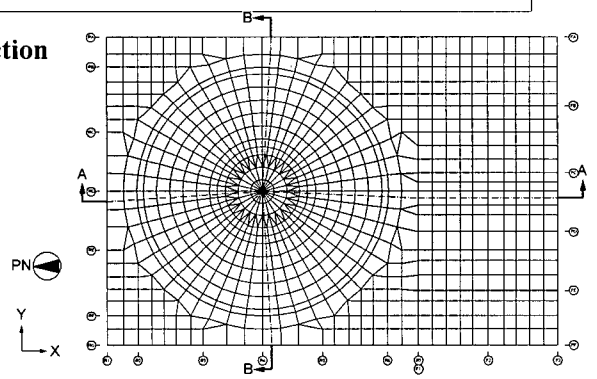


Figure 3.8-93(3)-c Comparison of Basemat Sectional Moments (soft x3)

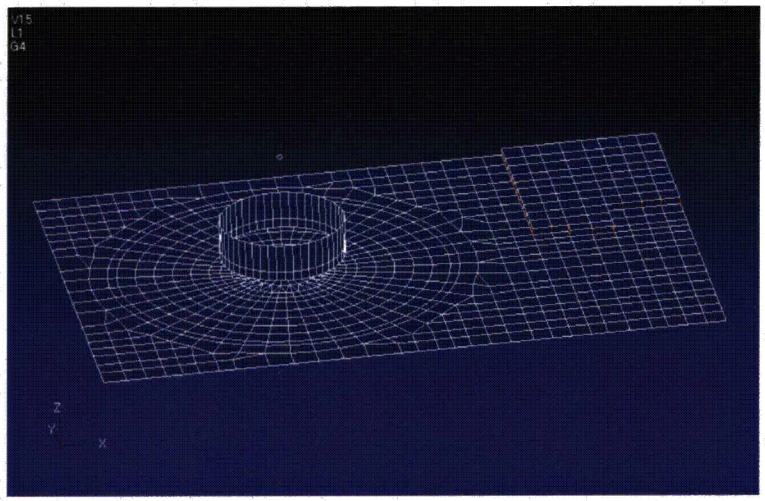


Figure 3.8-93(4)-a Case A (Step 1)

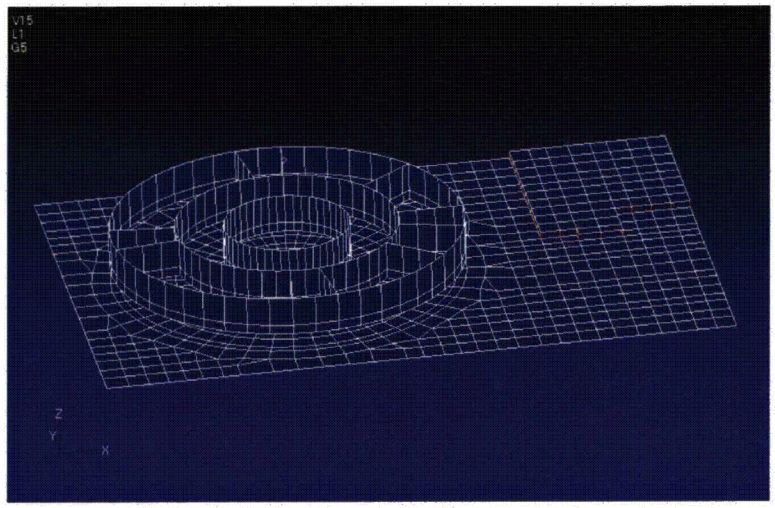


Figure 3.8-93(4)-b Case A (Step 2)

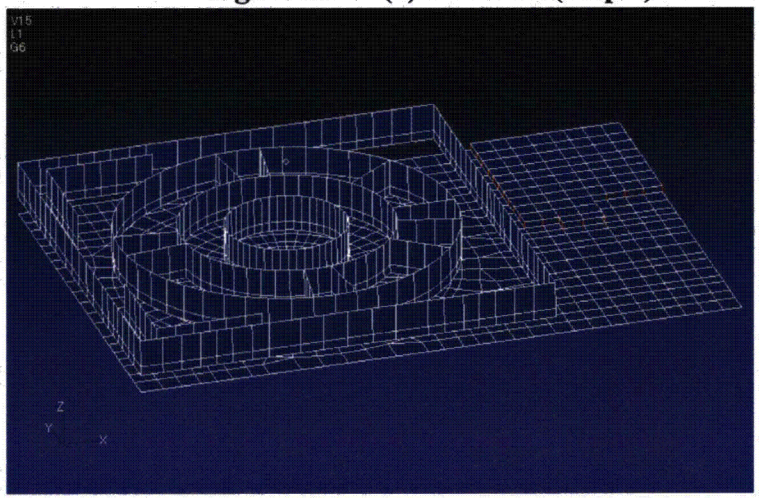


Figure 3.8-93(4)-c Case A (Step 3)

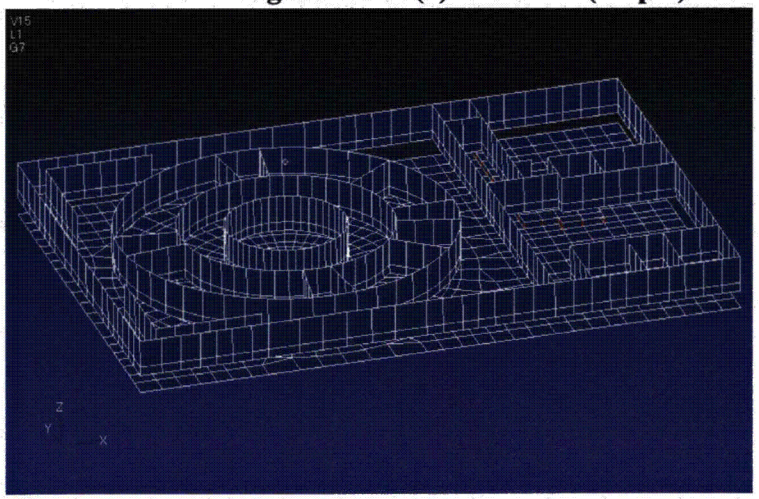


Figure 3.8-93(4)-d Case A (Step 4)

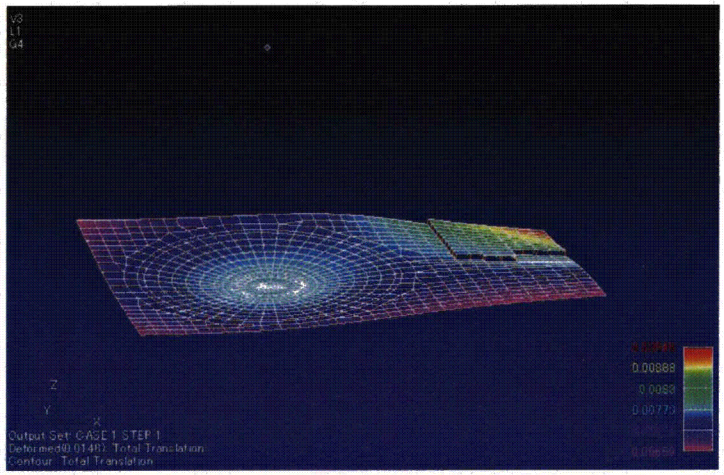


Figure 3.8-93(5) -a Deformation of basemat (CaseA - Step 1)

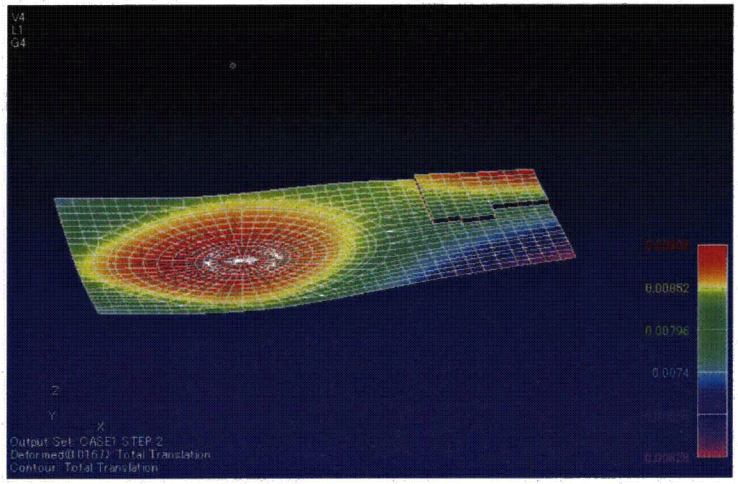


Figure 3.8-93(5) -b Deformation of basemat (CaseA - Step 2)

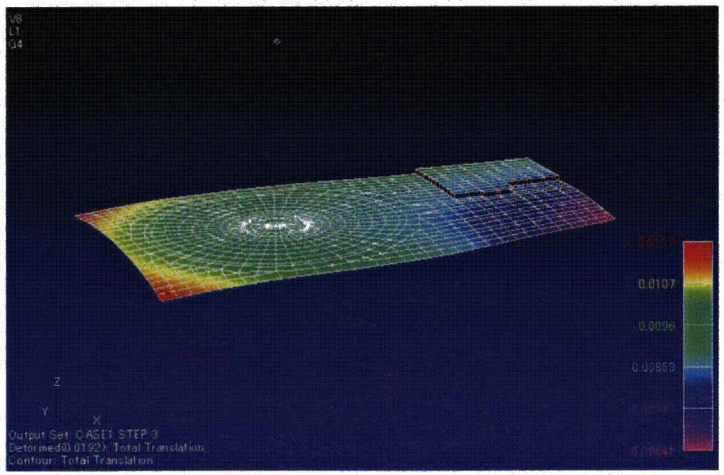


Figure 3.8-93(5) -c Deformation of basemat (CaseA - Step 3)

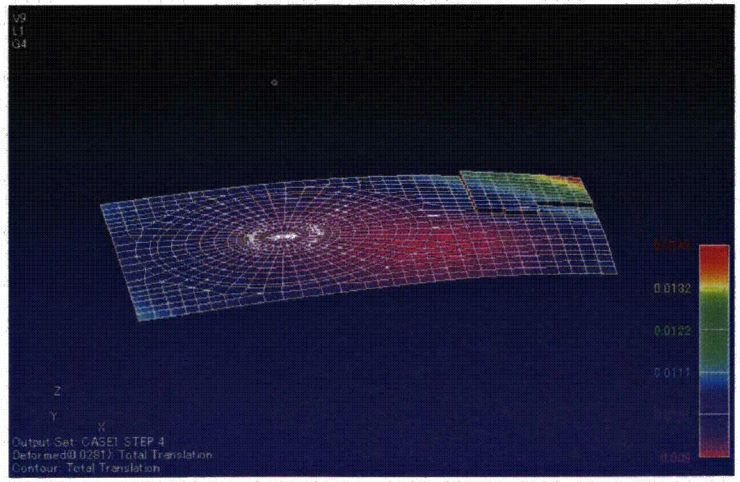


Figure 3.8-93(5) -d Deformation of basemat (CaseA - Step 4)

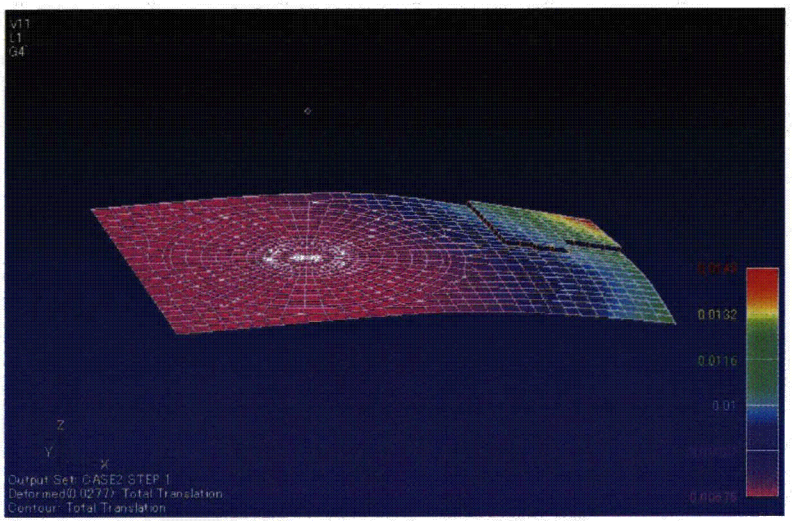


Figure 3.8-93(6) -a Deformation of basemat (CaseB - Step 1)

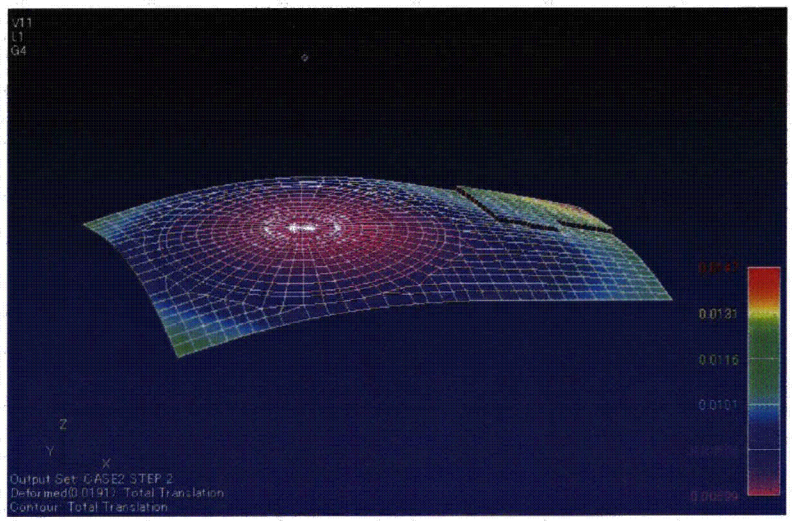


Figure 3.8-93(6) -b Deformation of basemat (CaseB - Step 2)

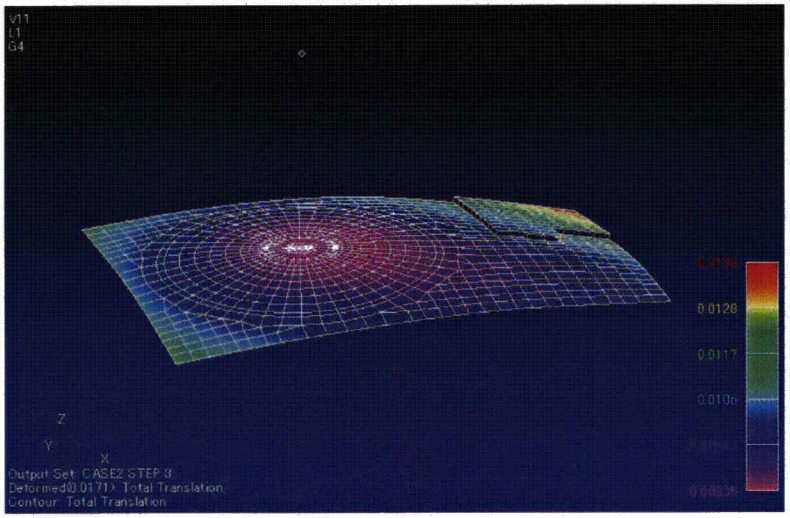


Figure 3.8-93(6) -c Deformation of basemat (CaseB - Step 3)

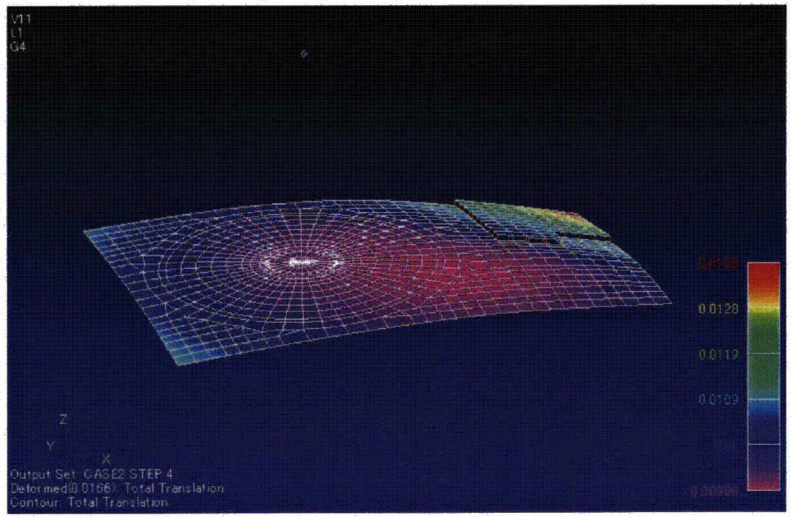
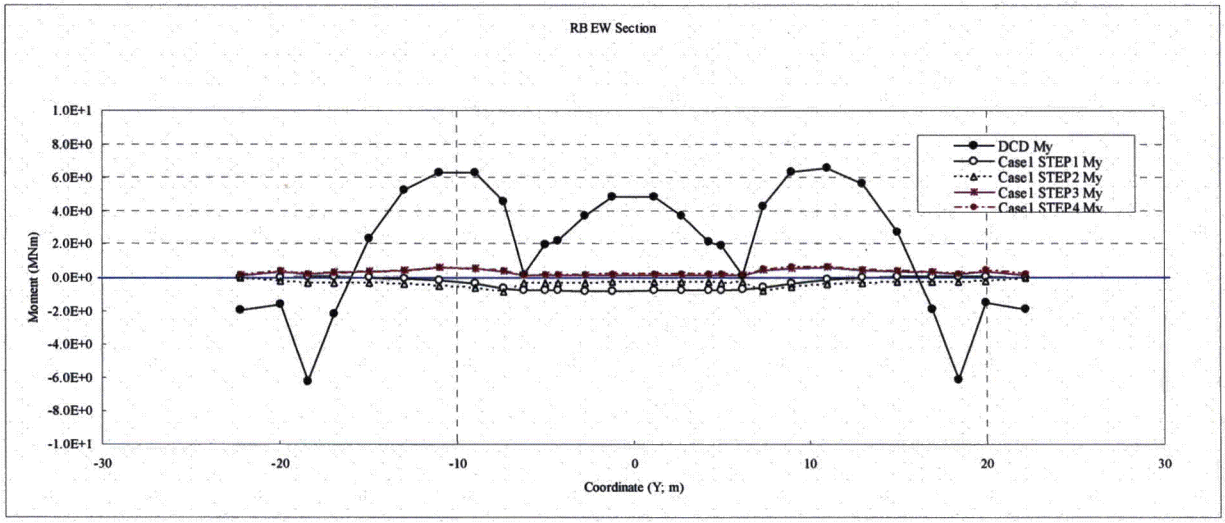
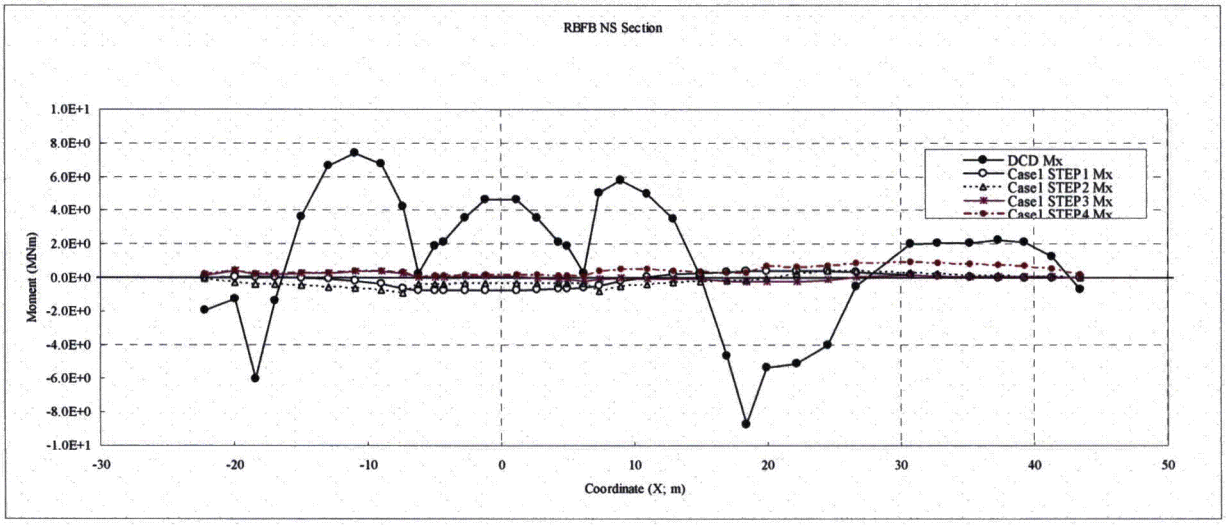


Figure 3.8-93(6) -d Deformation of basemat (CaseB - Step 4)





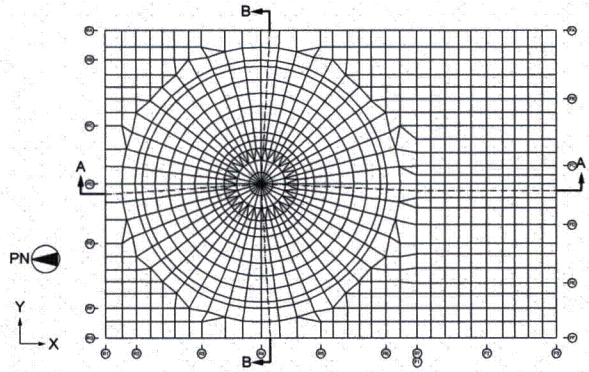
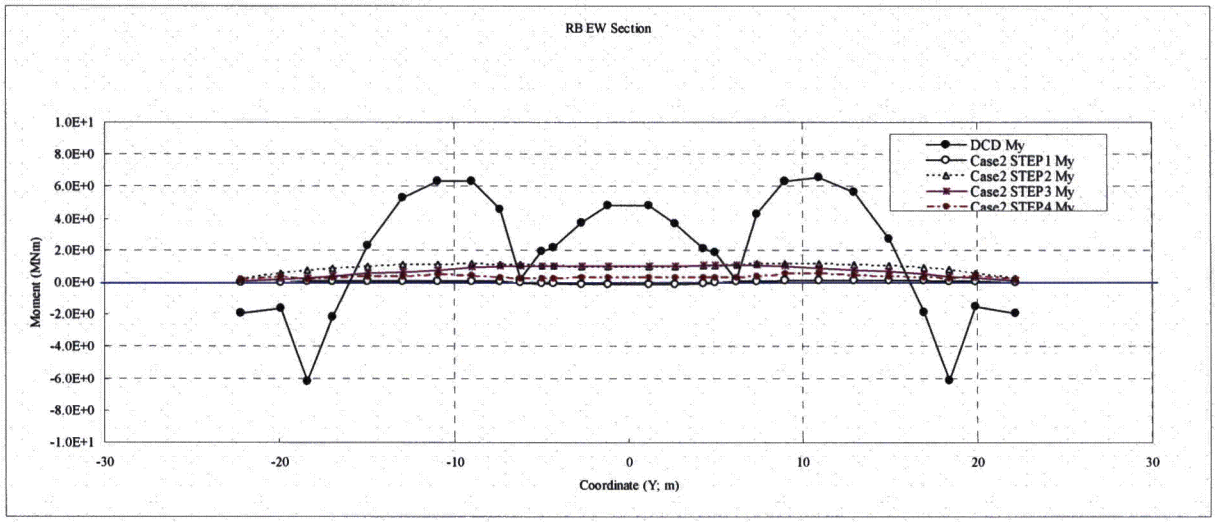
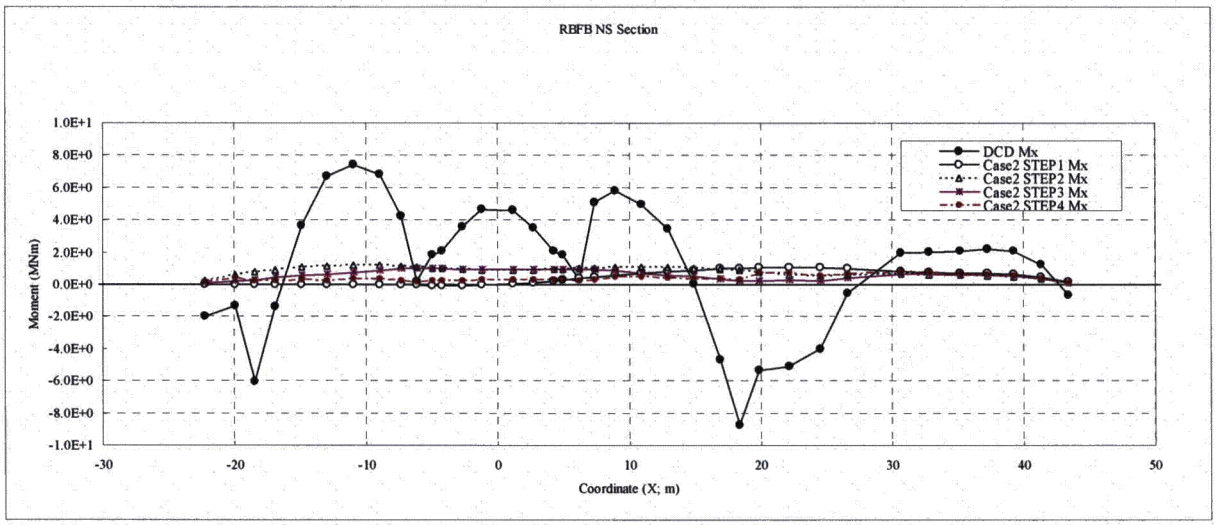


Figure 3.8-93(7) Comparison of Basemat Sectional Moments (Case A)





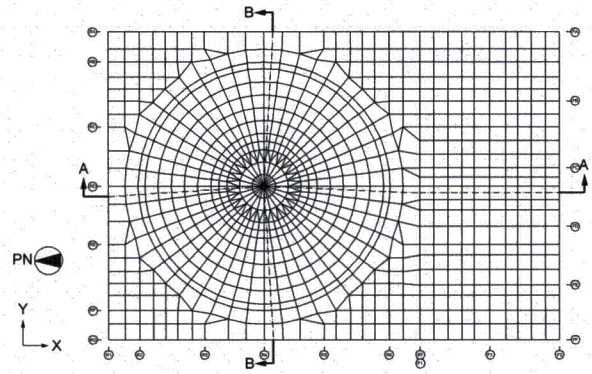


Figure 3.8-93(8) Comparison of Basemat Sectional Moments (Case B)

NRC RAI 3.8-93, Supplement 1

NRC Assessment Following the December 14, 2006 Audit

GE needs to explain why DCD Section 3.8.6.2 has been deleted and state where it will be documented in the DCD that "The COL holder will have to demonstrate that differential settlements at the site do not exceed this value by instituting a settlement monitoring program or justify in the COL why it would not be necessary." GE also needs to: (1) clarify "this value" in the previous sentence, (2) why only dead load is considered in the evaluation and clarify what loads are included in the dead load, (3) why is the pedestal area the only area considered to have a potential "hard spot," (4) explain the sentence "Assumed sequence is as follows, but this is imaginary since these portions are constructed in short time periods," (5) clarify if the two construction sequences (Case A and Case B) are a COL requirement, and if not, why not, and (6) why aren't hard spots considered in the construction phase. (7) In the evaluation for variation of horizontal soil springs, were the walls also reviewed in addition to the mat? (8) Regarding Fig. 3.8-93(3)-c, GE needs to explain why the soft X 3 case exceeds the base case.

During the audit, GE provided a draft supplemental response to address the above.

(1) For the settlement and differential settlement criteria, GE agreed to revise DCD Section 2.5 to specify, for all SC I structures, the allowable values that must be met by the COL applicant during the life of the plant for the particular site. The SC I structures are evaluated for these displacement limits and shown to meet design requirements. Also, DCD Section 3.8.5 will identify the need to satisfy these requirements and reference DCD Section 2.5. GE indicated that the precise values given in the RAI response will be reevaluated and will probably be increased since there is more margin.

(2) GE clarified in the draft supplemental response and during the audit why only dead load is considered.

(3) GE will address the concern that there are other horizontal variations of the soil springs (e.g., stiffer springs around the periphery, ...) to consider.

(4) GE clarified in the draft supplemental response and during the audit why the assumed sequence is considered to be "imaginary." That is because a conservative assumption was considered in the analysis.

(5) Regarding the need to specify general construction sequences in the DCD, which were the basis of the design, GE indicated that they will perform additional calculations to consider the effects of the construction sequence of the concrete mat pour and the effects on design. These evaluations will include consideration of the governing soil properties. GE expects that these bounding type calculations will show that the resulting forces and deformations are small. If so, GE will revise the DCD to indicate that the requirements for construction of the mat (based on these evaluations) will be specified in the construction specifications. If not, then a more detailed description of the construction requirements will be provided in the revised DCD.

(6) GE indicated that the hard spots were not considered for the construction phase analyses because the deformations and resulting loads were small and also, these construction related conditions are short term. The staff needs to review this position.

(7) GE indicated that they will review the results for the walls as well and provide their evaluation.

(8) GE indicated that they will review the results and provide their explanation.

GE Response

DCD Tier 2 Subsection 3.8.6.2 is deleted since an analysis of the settlement issue is performed using generic soil parameters, which are subject to confirmation by the COL applicant in DCD Tier 2 Chapter 2. Therefore, no additional COL requirements need to be stated in DCD Tier 2 Subsection 3.8.6.

(1) The allowable total and differential settlements within SC I buildings will be quantified in the next DCD Tier 2 revision. The following evaluation, *Assessment of Building Settlement*, discusses and sets limits for building settlement. The total settlement is defined as the maximum vertical displacement in the building basemat, and the differential settlement is defined as the maximum relative vertical displacement between two opposite corners along the longest dimension of the building basemat. The allowable differential settlement between the RBFB and CB is the relative displacement evaluated using the total settlements of two buildings.

(2) Only DL is considered because during construction of the mat, it imposes the worst loading condition. It consists of all permanent dead loads considered in the design for the "Normal Operation Phase" and the weights of the structures in accordance with the sequence considered in the "Construction Phase". Construction live loads on the order of 100 psf (4.8 kN/m^2) are ignored since the magnitude is only a small fraction (about 5%) of the basemat weight.

(3) Analyses for the inverted soil spring variation, i.e., stiffer springs around the peripheral area of the RPV Pedestal, were performed. The results are described in the following evaluation, *Basemat Design Considering Horizontal Variation of Soil Springs*. Based on the results, the DCD Tier 2 design envelopes the result of horizontal variation of soil spring under the condition that the ratio of the largest to the smallest shear wave velocity over the mat foundation width at foundation level does not exceed 1.7. This will be a COL item in DCD Tier 2 Chapter 2.

(4) Settlement is time dependent. Stiffening walls will be constructed within a few days after the mat pour. For conservatism in the analysis, it is assumed that the stiffening walls will be built a long time after the mat is poured.

(5) The construction sequence is not considered as a COL item since it is shown that under the worst loading condition, the mat can adequately handle the resulting stresses. Basemat construction sequence has no effect on the basemat design. The following evaluation, *Effect*

of Basemat Construction Sequence, clarifies the effect of the basemat concrete pour sequence to the basemat stress.

(6) The original response to NRC RAI 3.8-93 in MFN 06-407 shows that the Construction Phase is not as severe as the Normal Operation Phase for the uniform soil condition. Additional evaluation is performed to address the effect of the horizontal variation of soil springs on the basemat design during the Construction Phase. The following evaluation, *Basemat Design for Construction Phase Considering Horizontal Variation of Soil Springs*, shows the results of the hard spot condition, which confirms that the basemat stress during construction is smaller than the design stress.

(7) The evaluation, *Basemat Design Considering Horizontal Variation of Soil Springs*, mentioned in Item 3 above, also includes the resulting wall bending moments due to the horizontal variation the of soil springs. It is found that the "Soft Spot" condition controls the basemat design forces. Per Item 3 above, the COL applicant is to confirm the uniformity of the shear wave velocity at the foundation level for a given site.

(8) The bending moment distributions were compared for three cases of horizontal soil stiffness variation under the basemat in the original response to NRC RAI 3.8-93 in MFN 06-407. In the original response, the Softx3 case exceeded the base case. The evaluation mentioned in Item 3 above, *Basemat Design Considering Horizontal Variation of Soil Springs*, clarifies the result of horizontal variation of soil springs. Figure 3.8-93(24) shows the relative displacement normalized to the basemat displacement at the centerline position of the RB. It is found that the "Hard Spot" condition results in a different pattern of relative displacements when compared against the DCD Tier 2 analysis results. As a result, a limitation for the maximum variation of horizontal soil stiffness in terms of shear wave velocity is imposed as a COL item stated in Item 3 above.

Evaluation for NRC RAI 3.8-93 (1)

Assessment of Building Settlement

1. Scope

The uniform settlement and differential settlement criteria for the C-I buildings will be specified in DCD for the COL applicant.

This section provides the results of the study regarding the allowable values of the settlement and differential settlement using the global FE model. The magnitudes of settlement are related to soil conditions. Soft soil is considered since it has the most settlement potential. To bound the possible horizontal variation in soil stiffness, two distributions are assumed which are uniform and linear gradient as shown in Figure 3.8-93 (9).

2. Settlement for Uniform Soil Conditions

Evaluations for uniform soil conditions are performed using soil springs corresponding to the soft soil whose shear wave velocity is Vs = 300 m/sec, i.e., soil springs used in the DCD design, since the softer soil generates the larger settlement.

Table 3.8-93(1) shows the maximum and average settlements obtained by FE analyses. The average settlement is the average of vertical displacements at four corners of a building.

3. Settlement for Gradient Soil Conditions

3-1. Design considerations

The gradient stiffness distribution is to address the settlement effect of non-uniform distribution of the foundation soil on the basemat design. Estimated differential settlements are used as the allowable values for the DCD. The differential settlement is specified over the longest dimension of a basemat.

3-2. Analysis condition

Analyses are performed under linearly varying stiffness of soil condition (gradient condition), and the results are compared to the DCD design. Analytical conditions are as follows:

- Assumed differential settlement:

  RBFB: 3.0 inches, CB: 0.5 inches.
- FEM Model: Global FEM Model (DCD Design Model)
- Soil Condition: A varying soil spring stiffness is assumed as shown in Figure 3.8-93 (9). The soil spring moduli for gradient stiffness distribution are determined to yield the assumed differential settlements along four directions, E-W, W-E, N-S and S-N. The stiffness of soil spring at the center of the basemat is set to be the same as the uniform soil condition mentioned above.
- Load: Dead Load

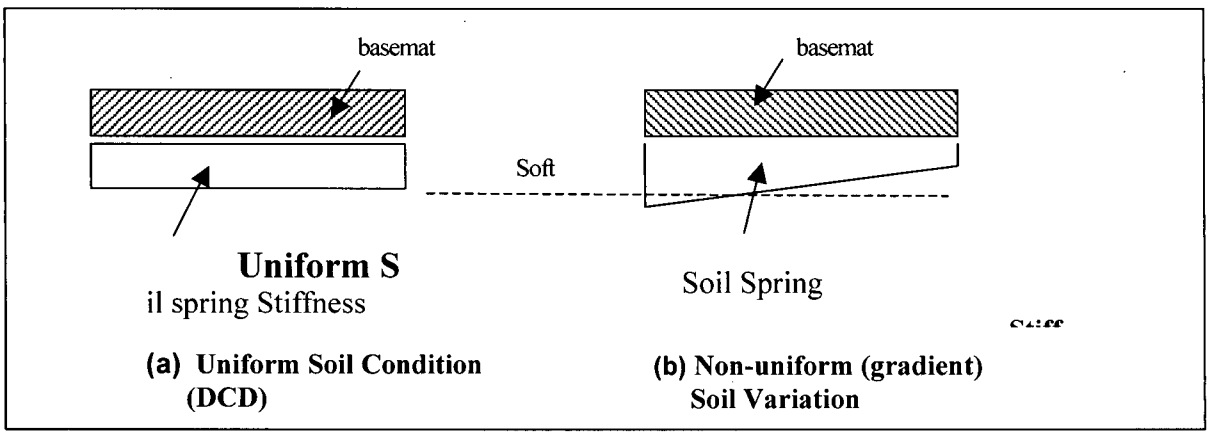


Figure 3.8-93 (9) Soil Conditions

3-3. Analysis result

Table 3.8-93(1) includes the maximum and average settlements obtained by FE analyses for gradient soil conditions. Table 3.8-93(2) summarizes the differential settlements within buildings and between buildings that are determined according to the analysis results. The

differential settlement between buildings (RB/FB and CB) shown in Table 3.8-93(2) is the difference between the maximum settlements of the RB/FB and CB which are shown in Table 3.8-93(1). Figures 3.8-93 (10) and (11) show the settlement of buildings. In these figures settlement values are shown at the center of the building, while the maximum settlements indicated in Table 3.8-93(1) occur at any corner of the building. Figures 3.8-93(12) and (13) show the bending moment of the basemat compared to the DCD. It is noted that the effects on the basemat stresses due to the differential settlement are negligible. Therefore, the calculated maximum and differential settlements are used as the allowable values for DCD.

4. Conclusion

The maximum and average settlements under gradient condition shown in Table 3.8-93(1) are used as the allowable maximum settlement within buildings.

The differential settlement obtained in the analyses for the gradient soil conditions shown in Table 3.8-93(2) is used as the allowable differential settlement within a building.

The differential settlement between buildings (RB/FB and CB) shown in Table 3.8-93(2) is used as the allowable value.

Table 3.8-93(1) Calculated Settlement of Buildings

Building		Uniform Soil Condition	Gradient Soil Condition
RB/FB	Maximum	74 mm (2.9 in.)	103 mm (4.0 in.)
	Average*	53 mm (2.1 in.)	65 mm (2.6 in.)
CB	Maximum	11 mm (0.43 in.)	18 mm (0.7 in.)
	Average*	10 mm (0.4 in.)	11 mm (0.43 in.)

* Settlement values of four corner are averaged

Table 3.8-93(2) Calculated Differential Settlement

Building	Differential Settlement within Building	Differential Settlement between Buildings
RB/FB	77 mm (3.0 in.)	85 mm (3.3 in.)
CB	13 mm (0.5 in.)	

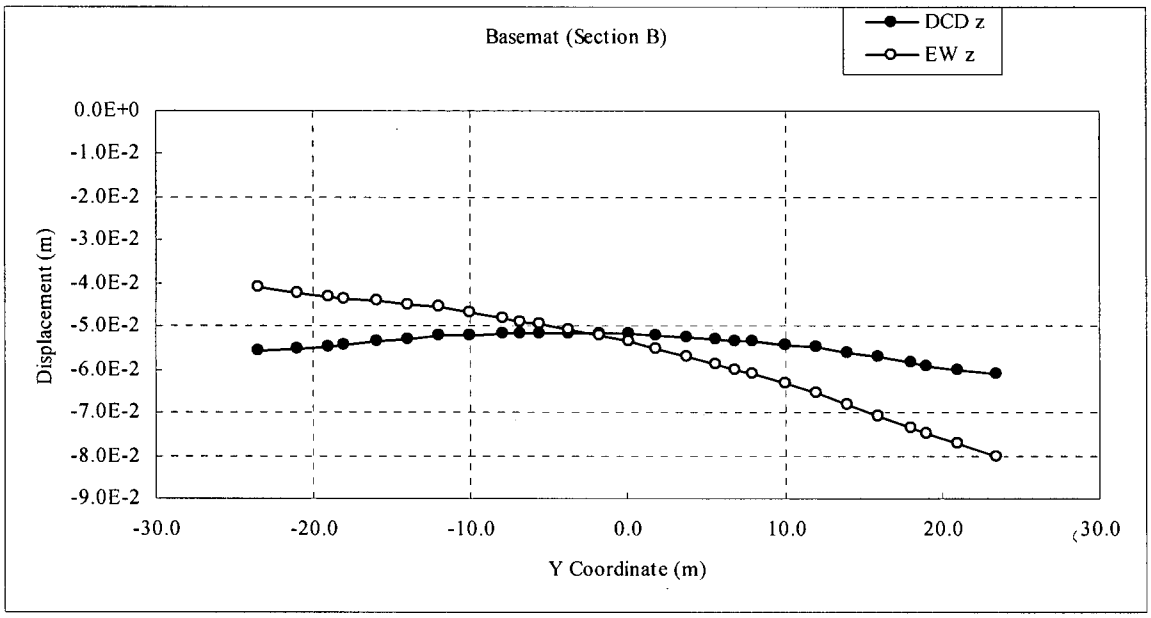


Figure 3.8-93 (10)-a Comparison of Settlement (RBFB, E-W direction)

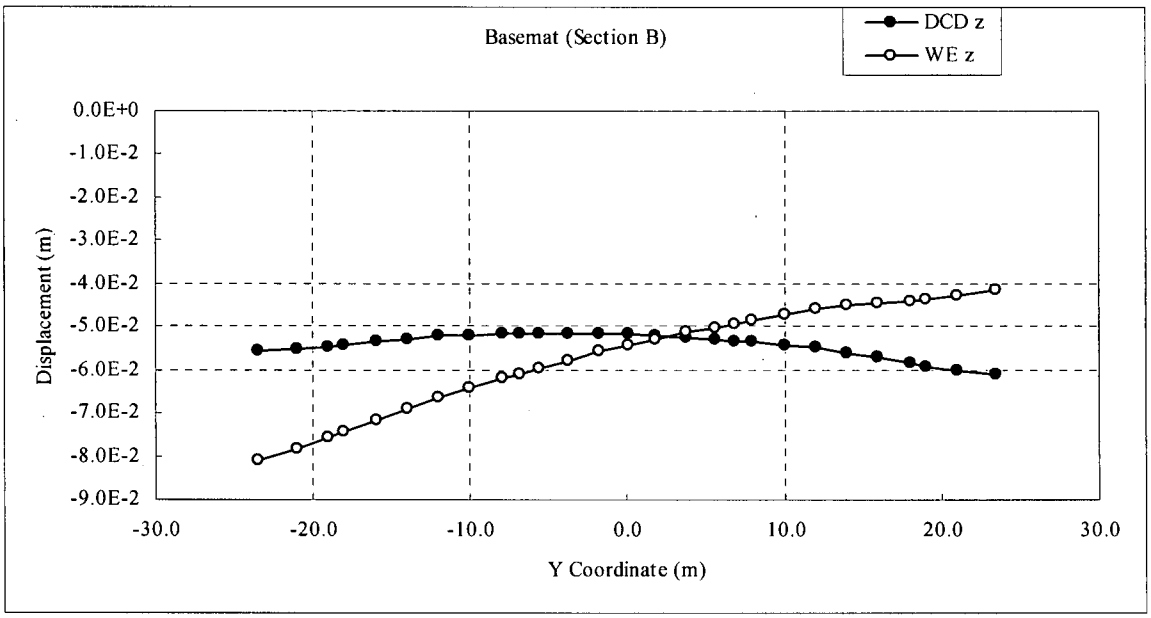
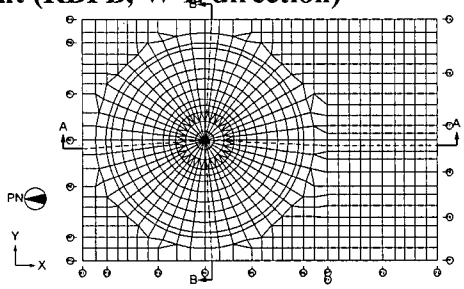


Figure 3.8-93 (10)-b Comparison of Settlement (RBFB, W-E direction)



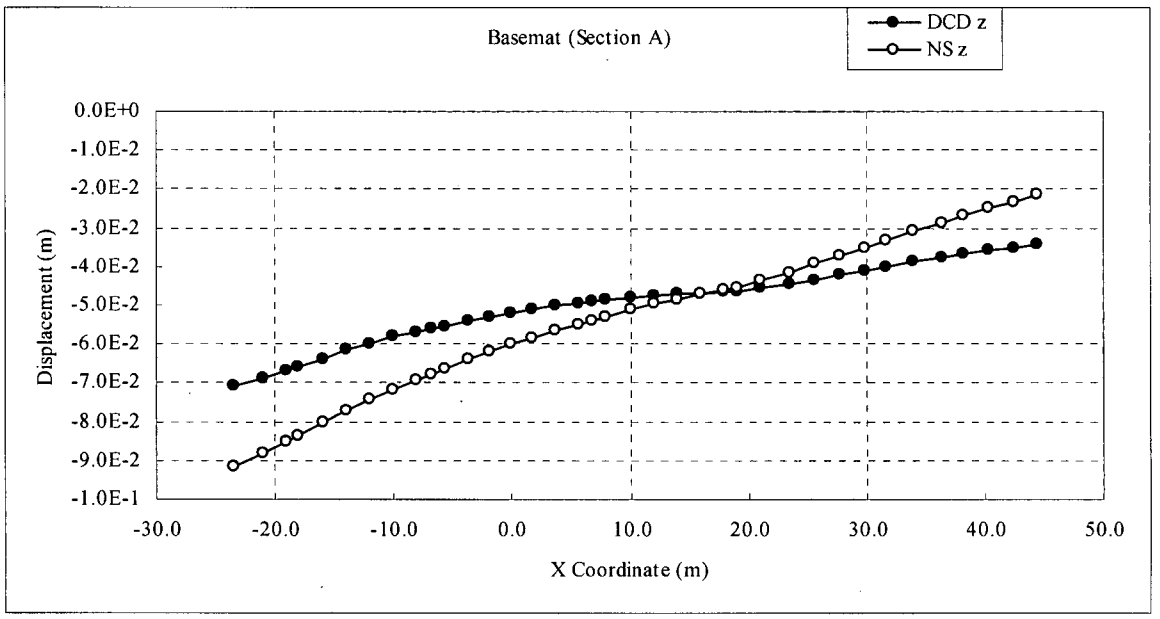


Figure 3.8-93 (10)-c Comparison of Settlement (RBFB, N-S direction)

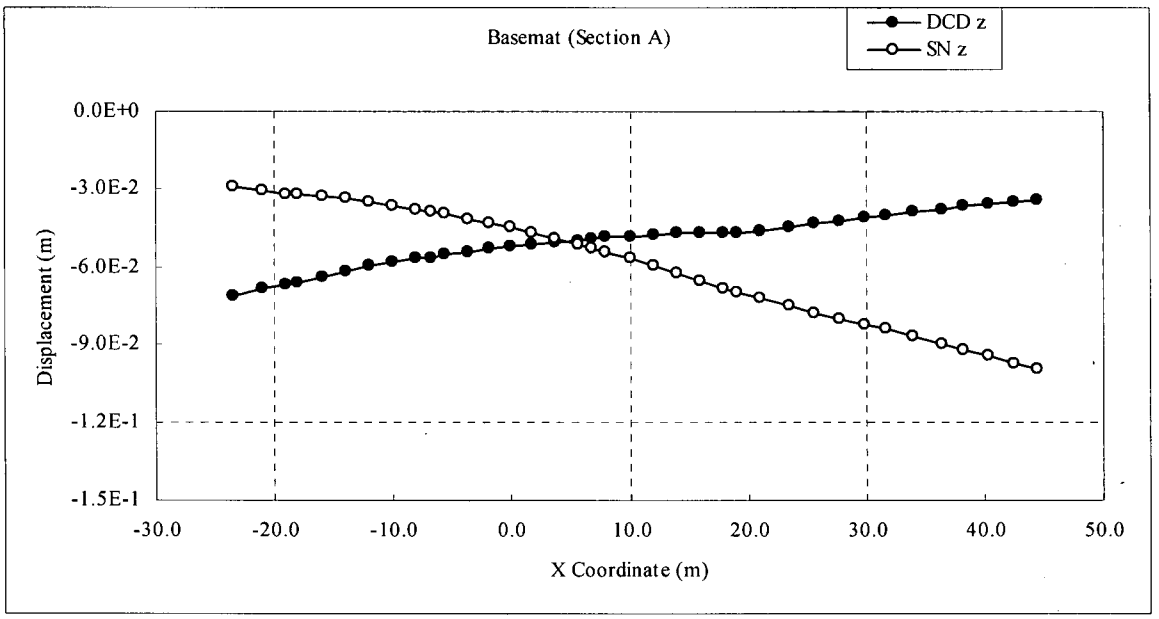
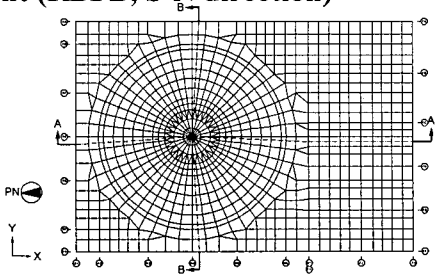


Figure 3.8-93 (10)-d Comparison of Settlement (RBFB, S-N direction)



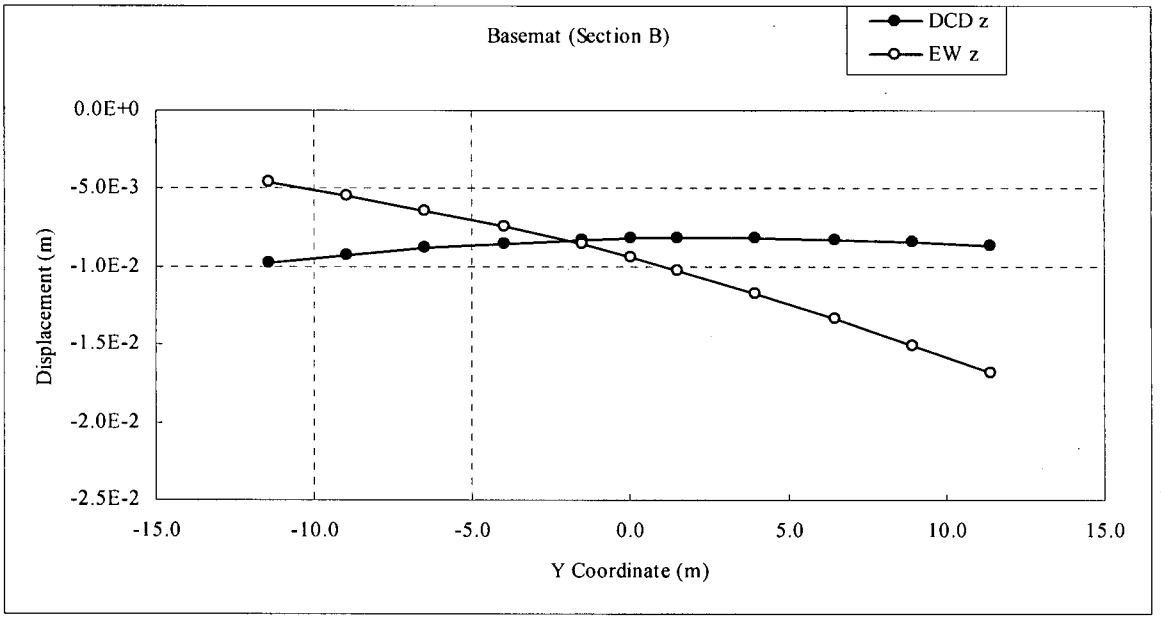


Figure 3.8-93 (11)-a Comparison of Settlement (CB, E-W direction)

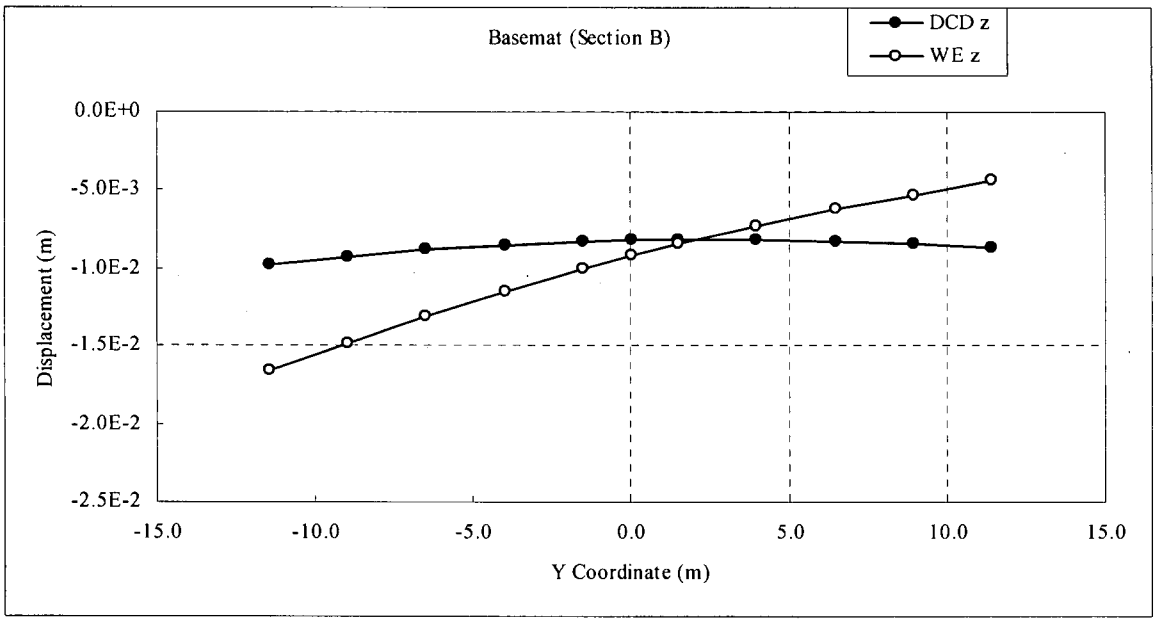
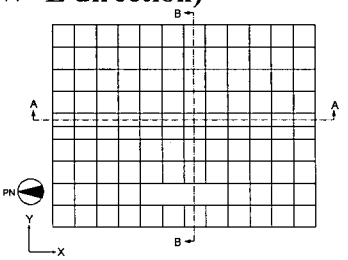


Figure 3.8-93 (11)-b Comparison of Settlement (CB, W -E direction)



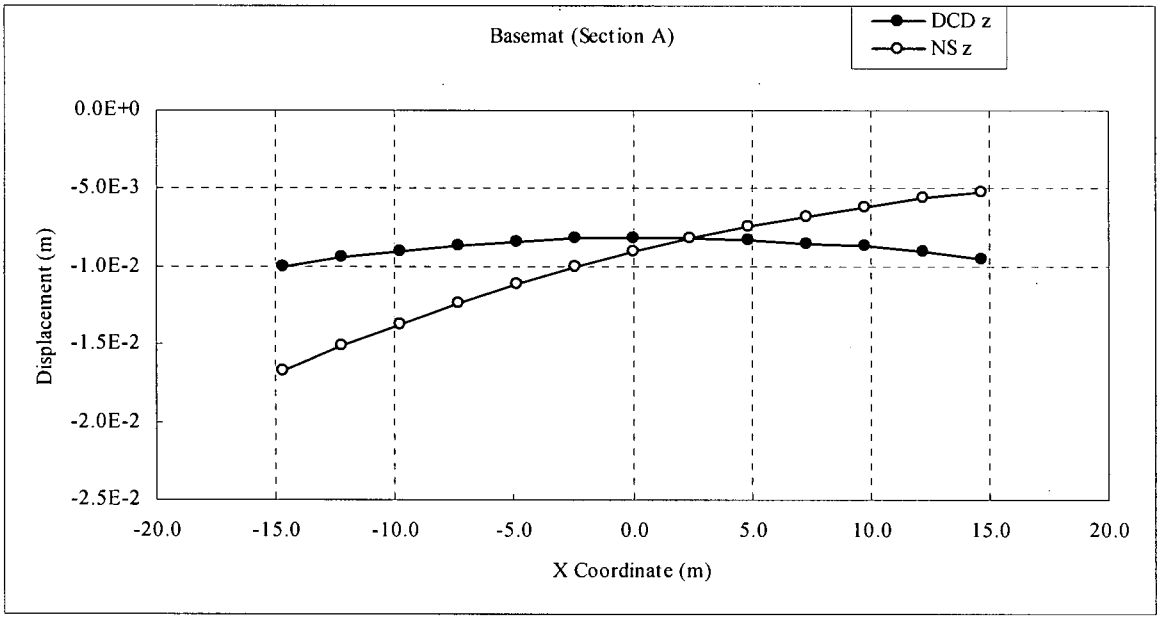


Figure 3.8-93 (11)-c Comparison of Settlement (CB, N-S direction)

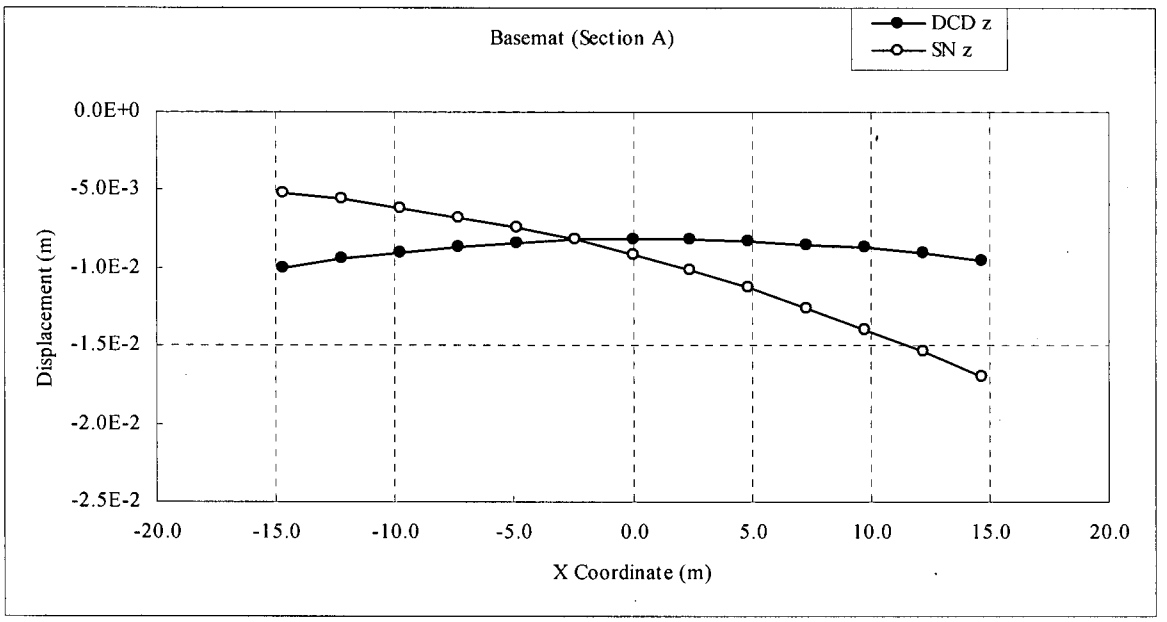
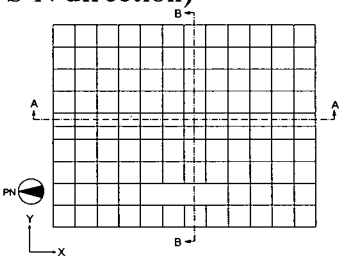
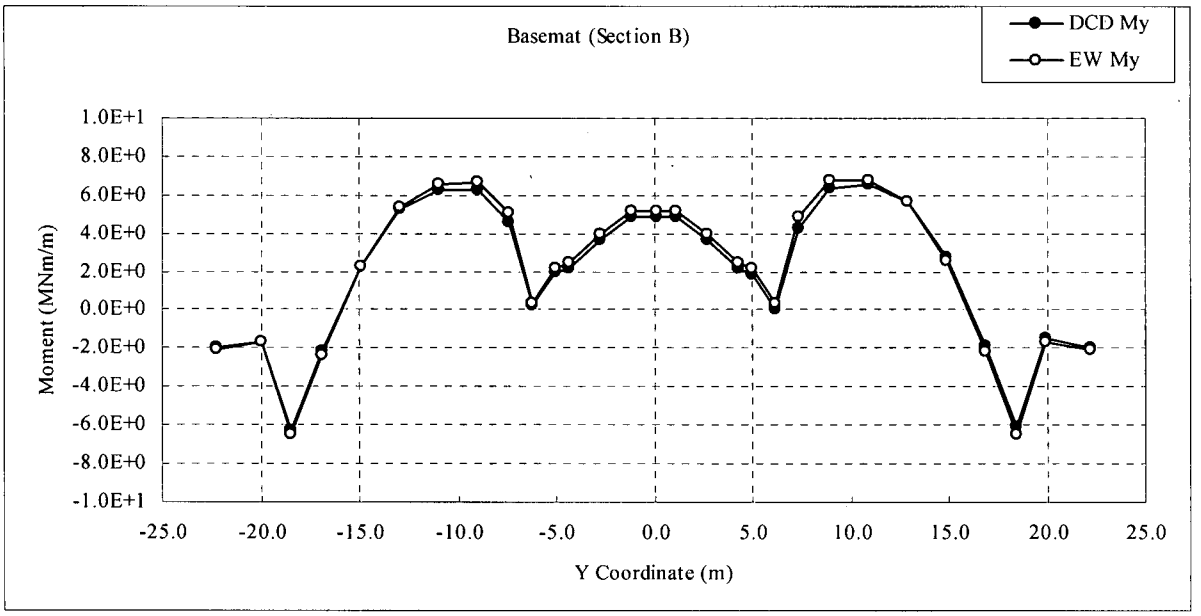
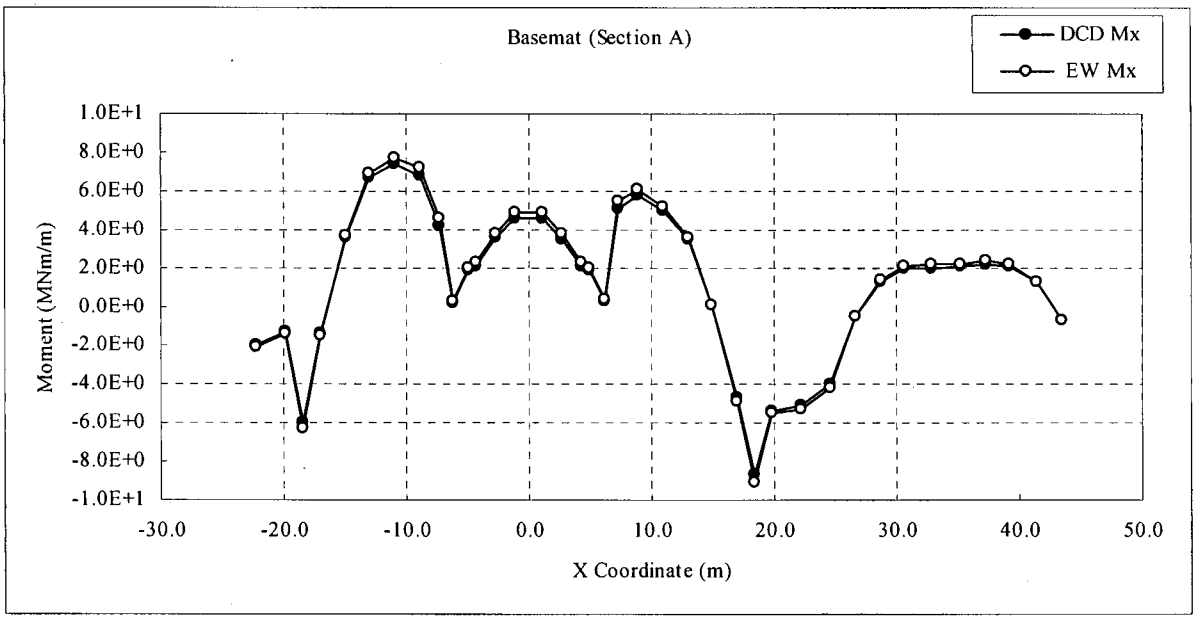


Figure 3.8-93 (11)-d Comparison of Settlement (CB, S-N direction)



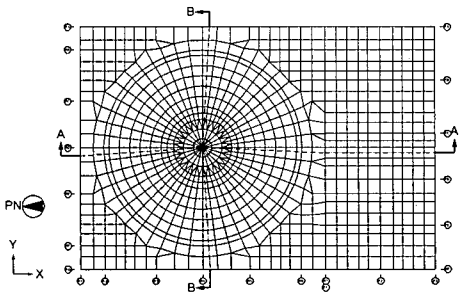


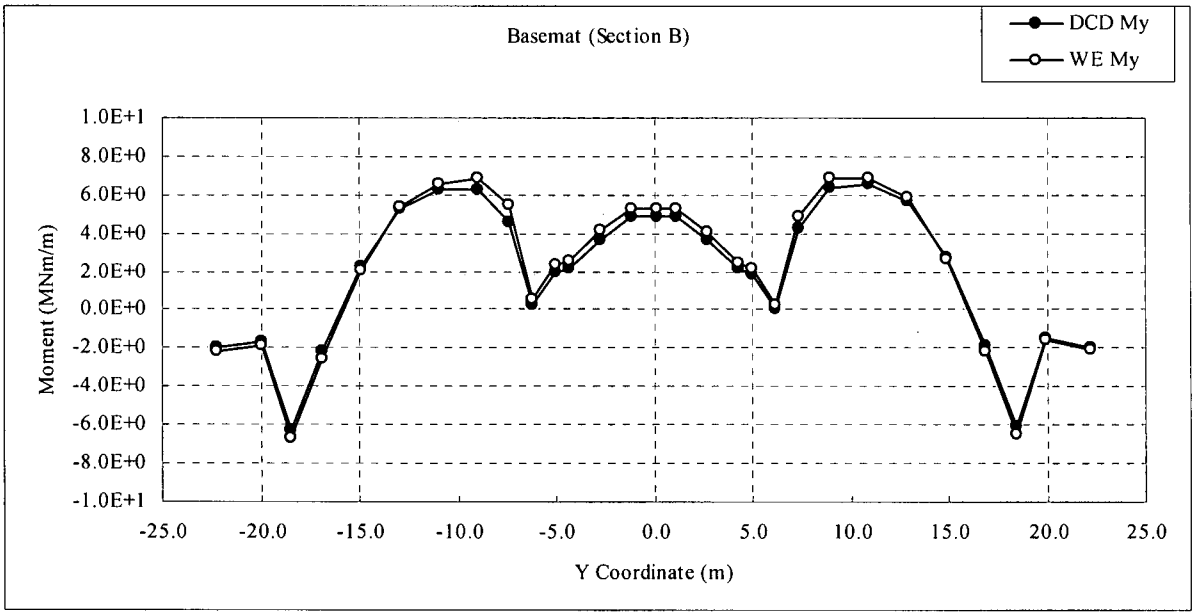
(a) My in E-W Section



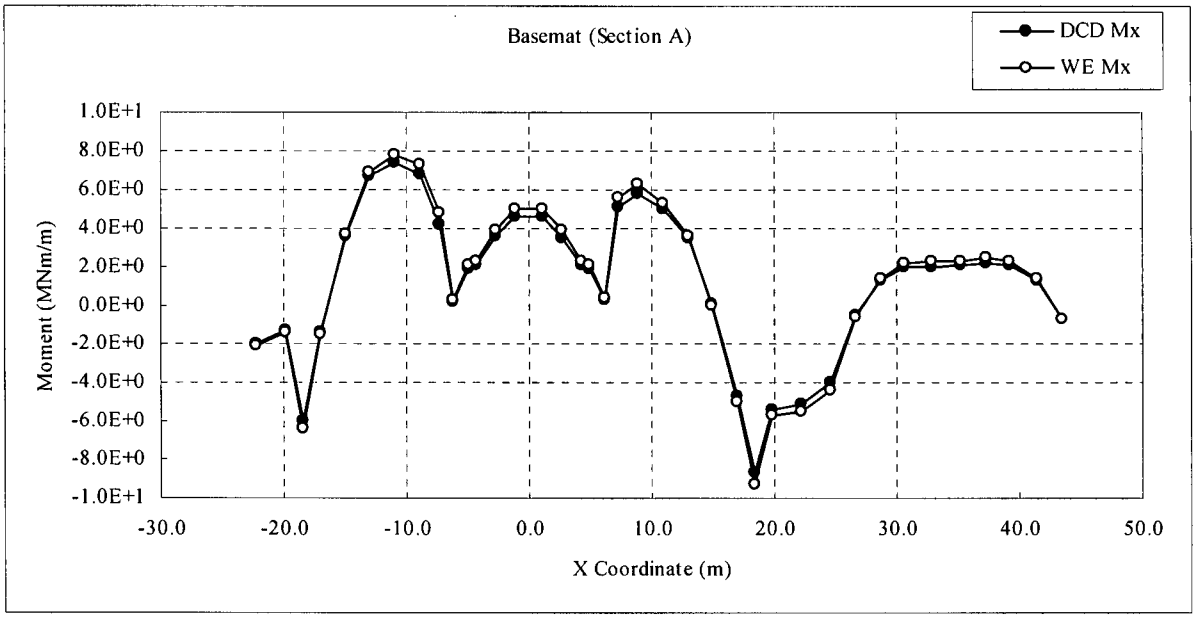
(b) Mx in N-S Section

Figure 3.8-93 (12)-a Comparison of Basemat Sectional Moments (RBFB, E-W direction)



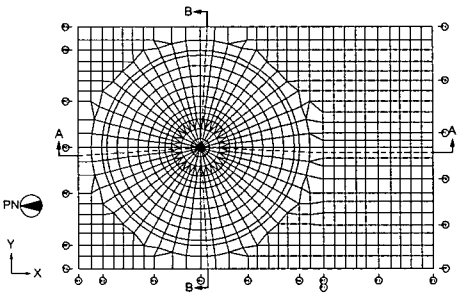


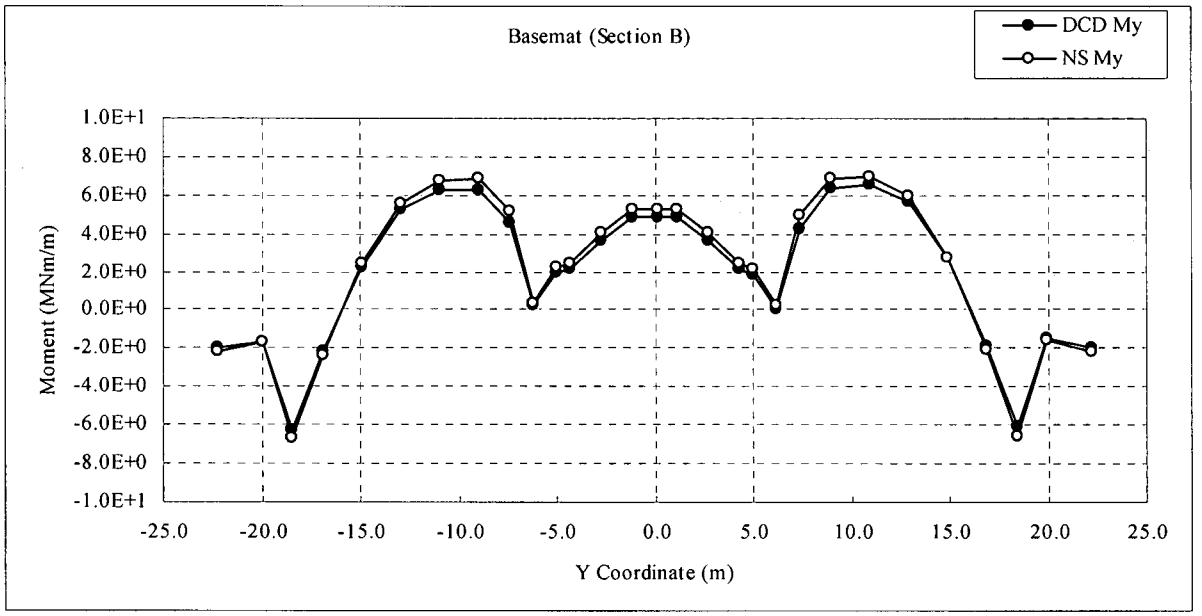
(a) My in E-W Section



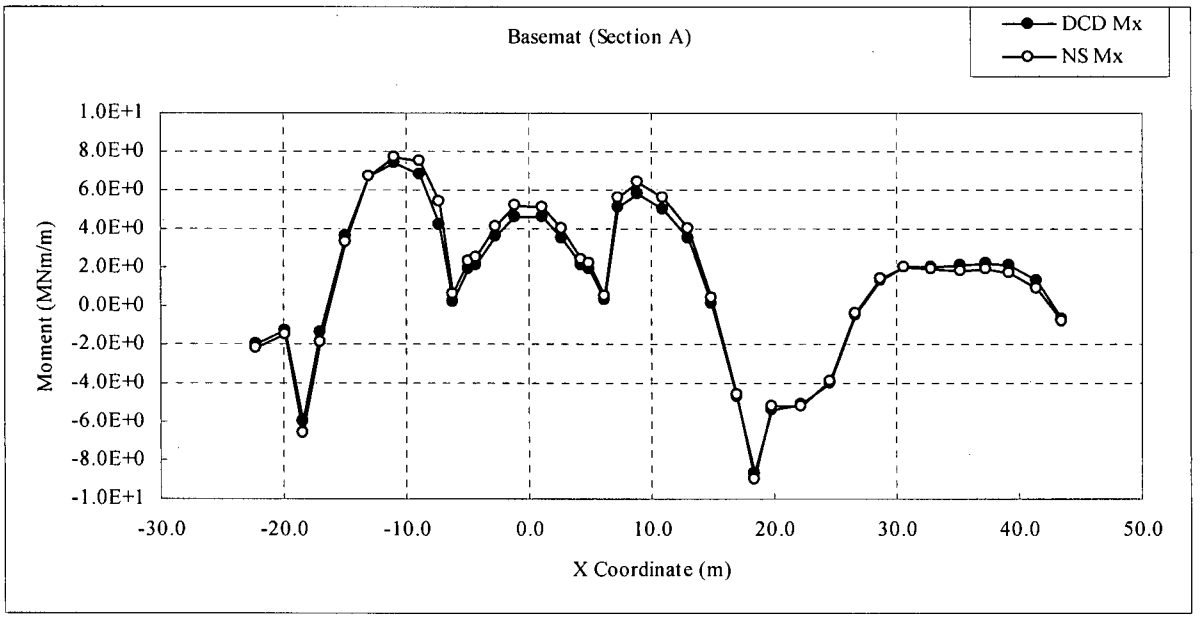
(b) Mx in N-S Section

Figure 3.8-93 (12)-b Comparison of Basemat Sectional Moments (RBFB, W-E direction)



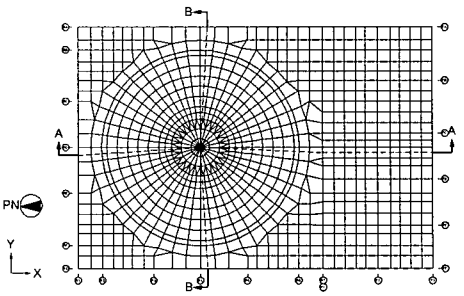


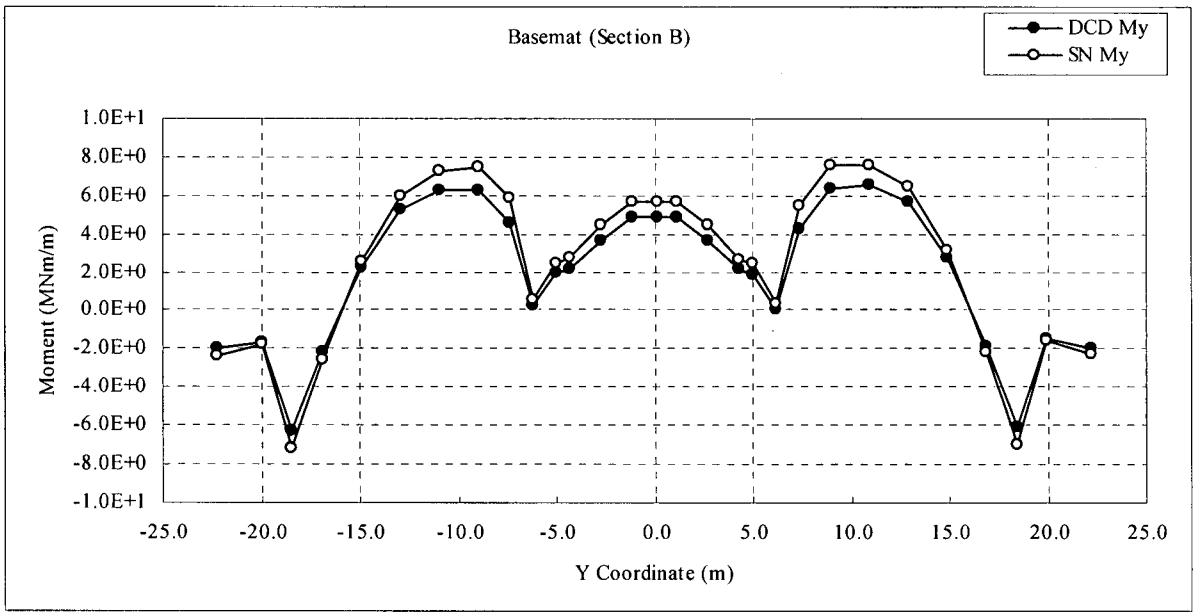
(a) My in E-W Section



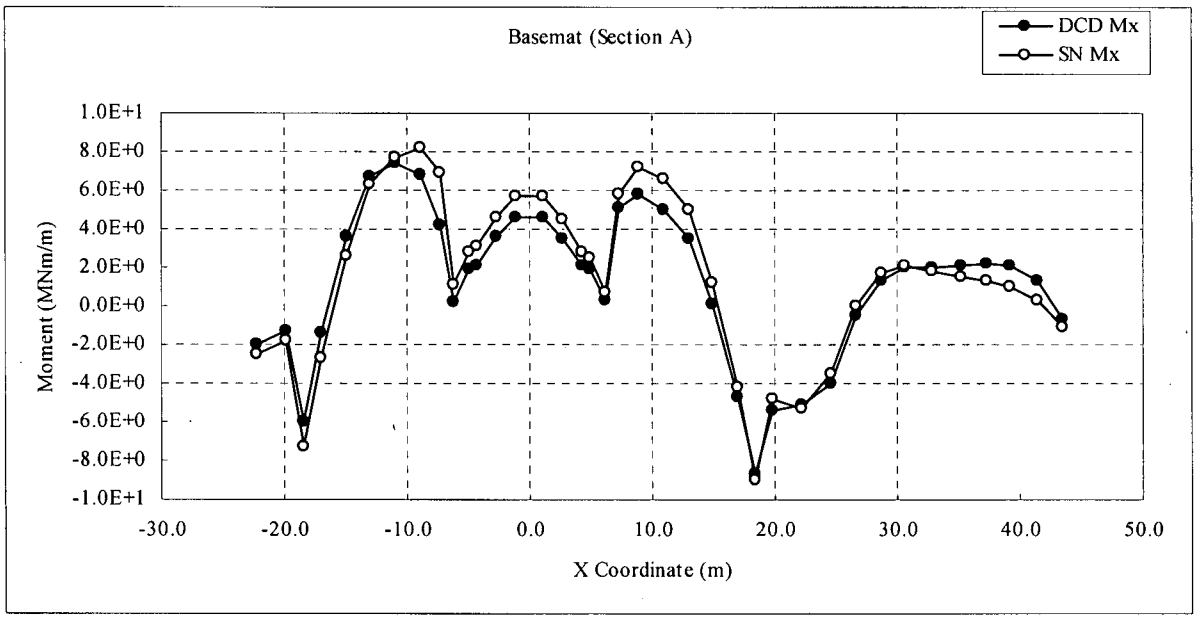
(b) Mx in N-S Section

Figure 3.8-93 (12)-c Comparison of Basemat Sectional Moments (RBFB, N-S direction)



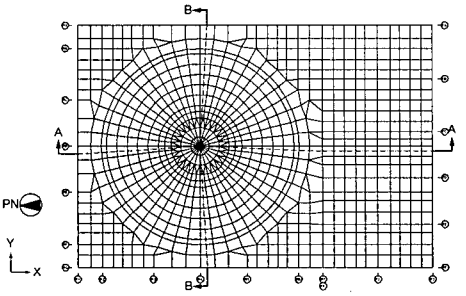


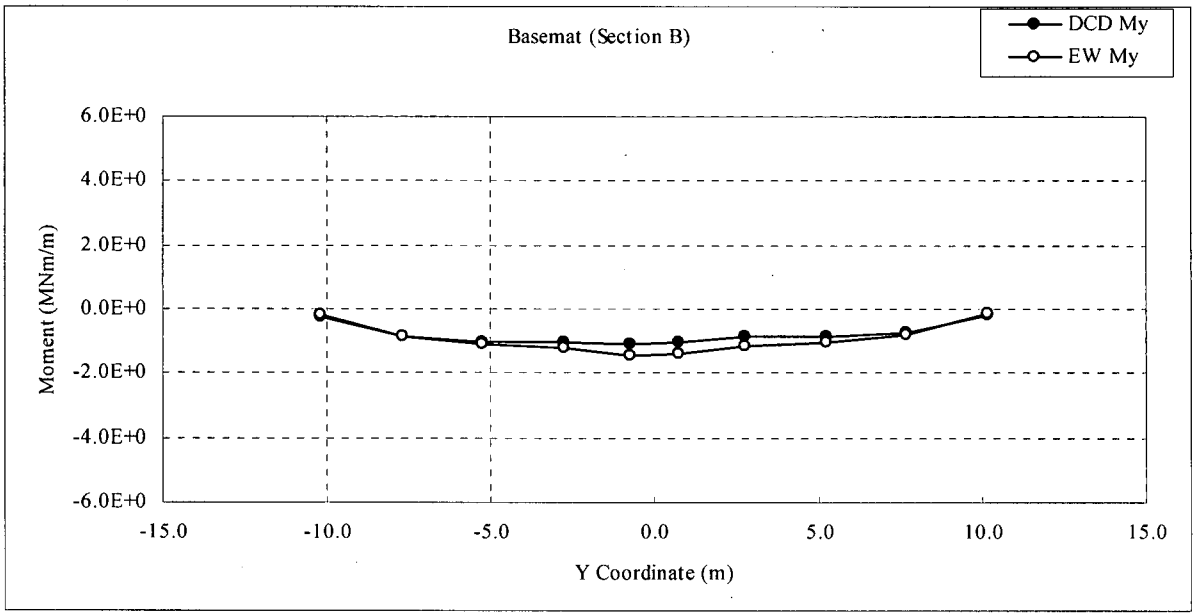
(a) My in E-W Section



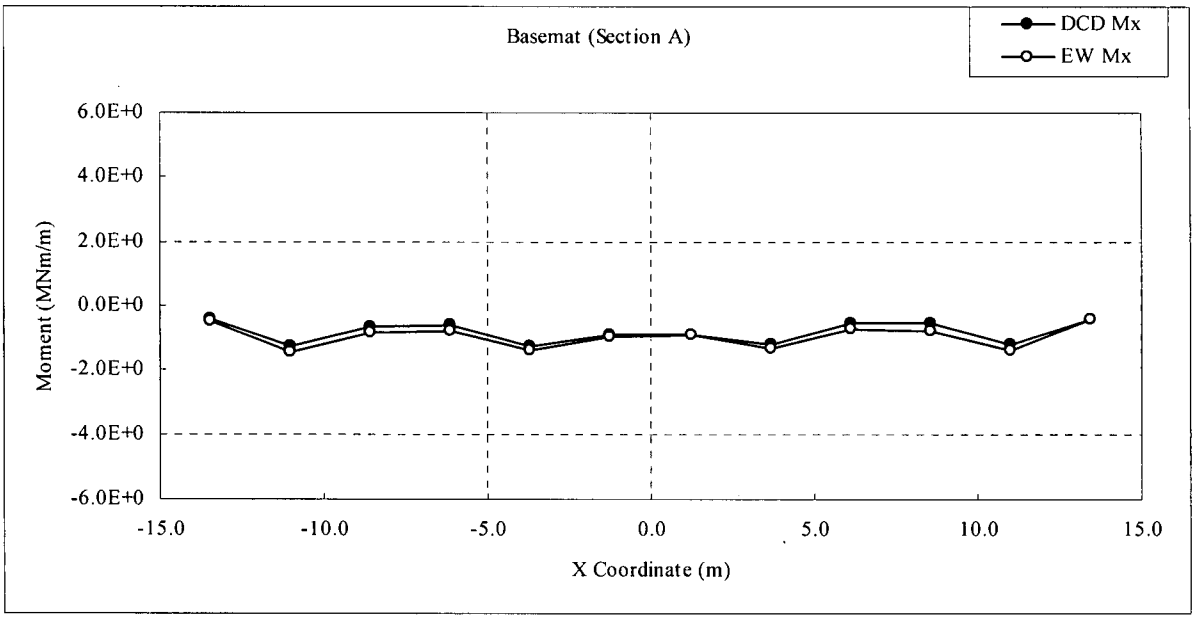
(b) Mx in N-S Section

Figure 3.8-93 (12)-d Comparison of Basemat Sectional Moments (RBFB, S-N direction)



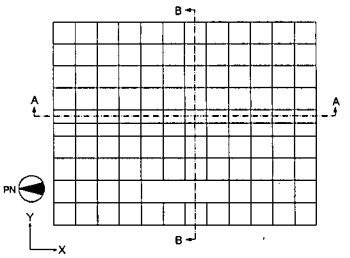


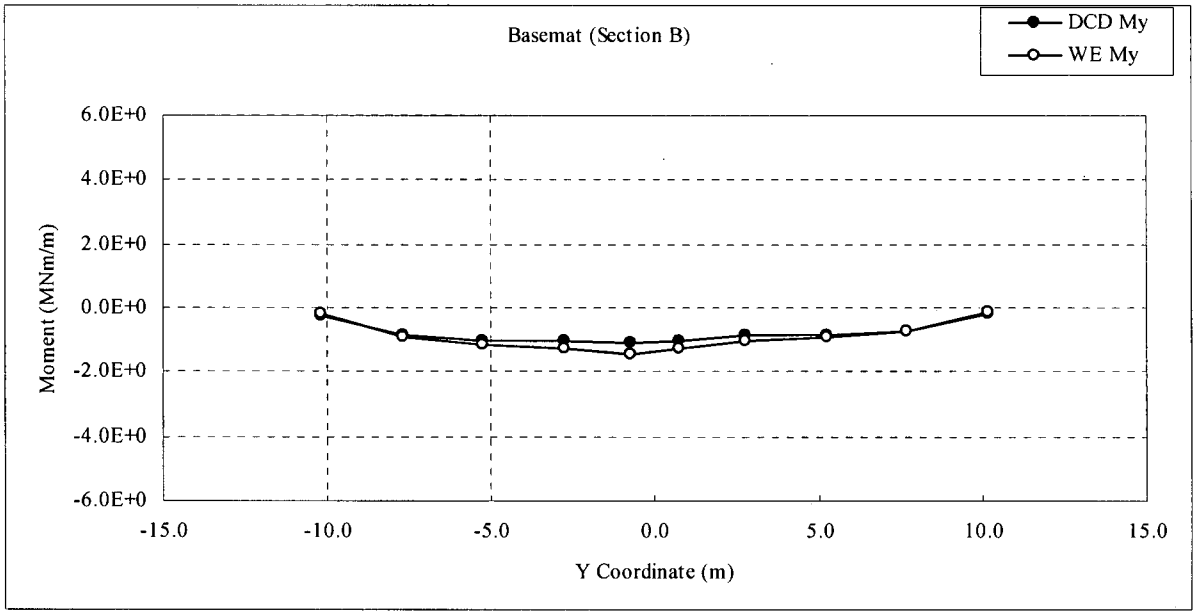
(a) My in E-W Section



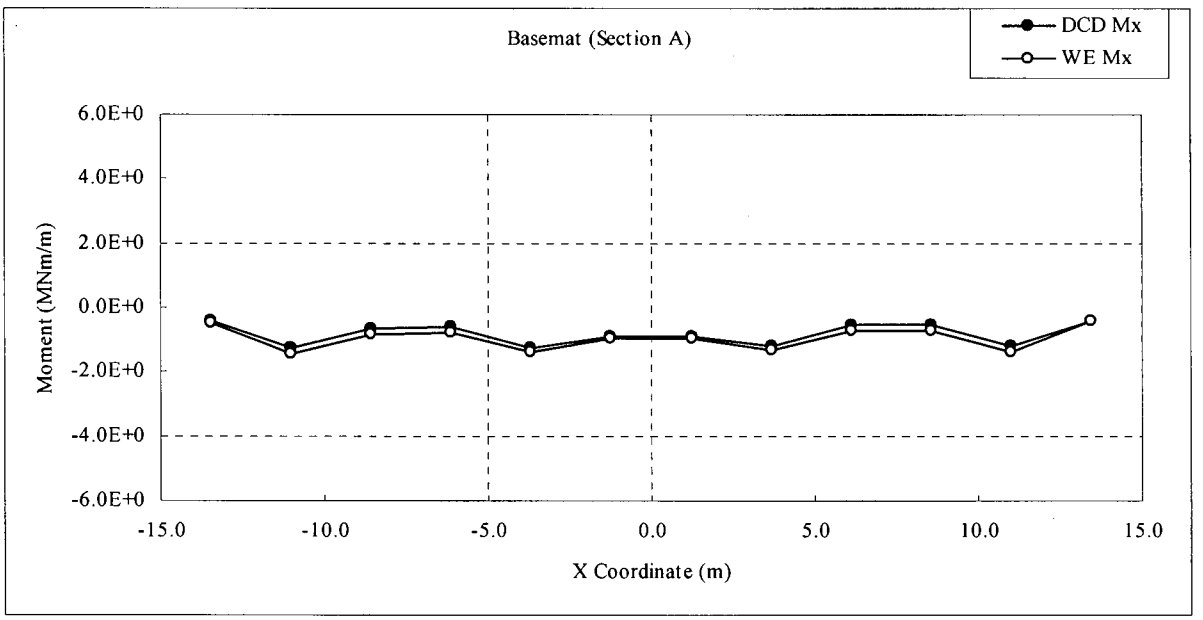
(b) Mx in N-S Section

Figure 3.8-93 (13)-a Comparison of Basemat Sectional Moments (CB, E-W direction)



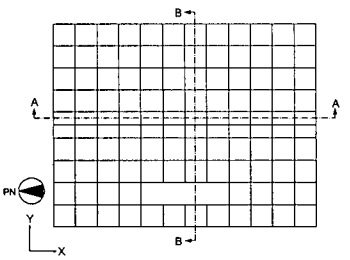


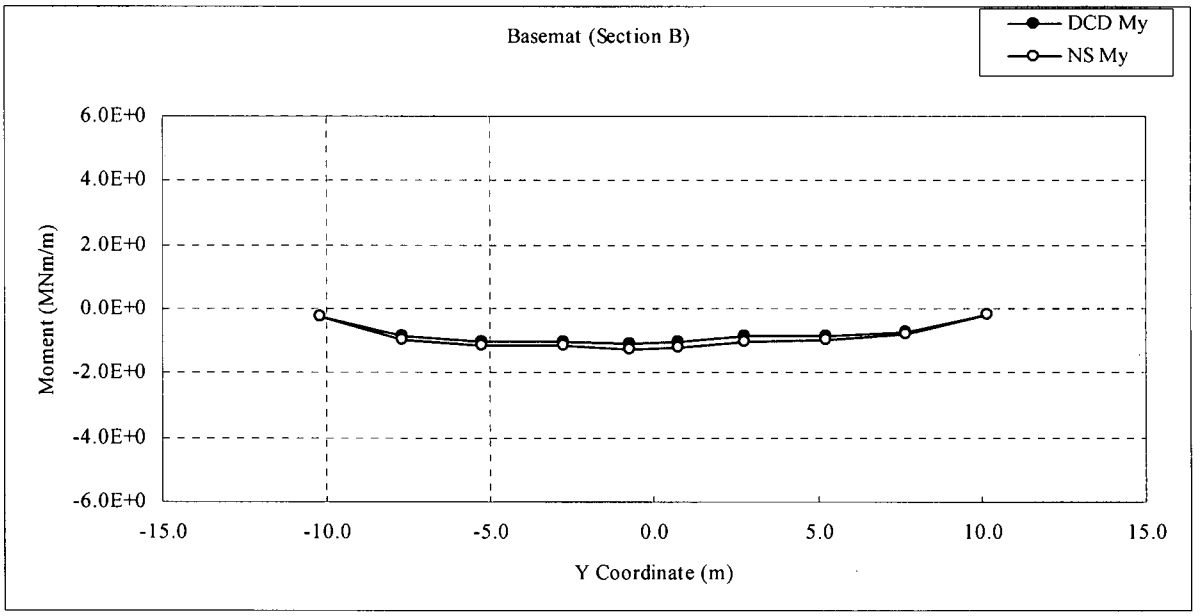
(a) My in E-W Section



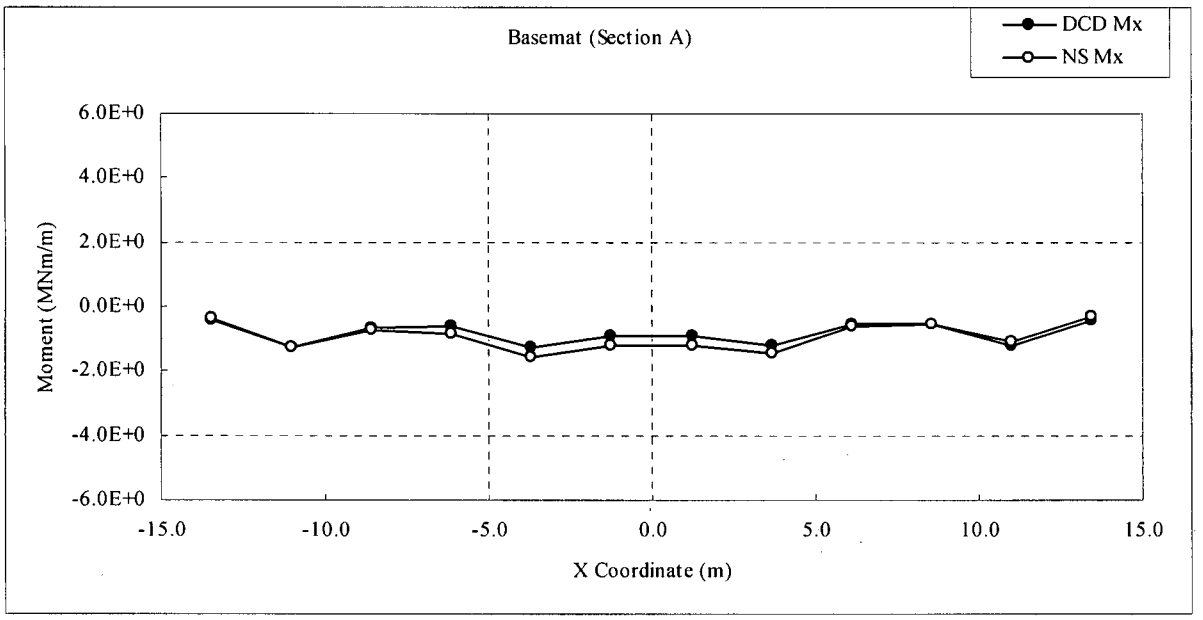
(b) Mx in N-S Section

Figure 3.8-93 (13)-b Comparison of Basemat Sectional Moments (CB, W-E direction)



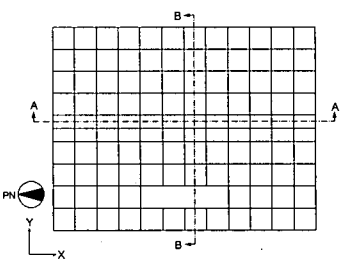


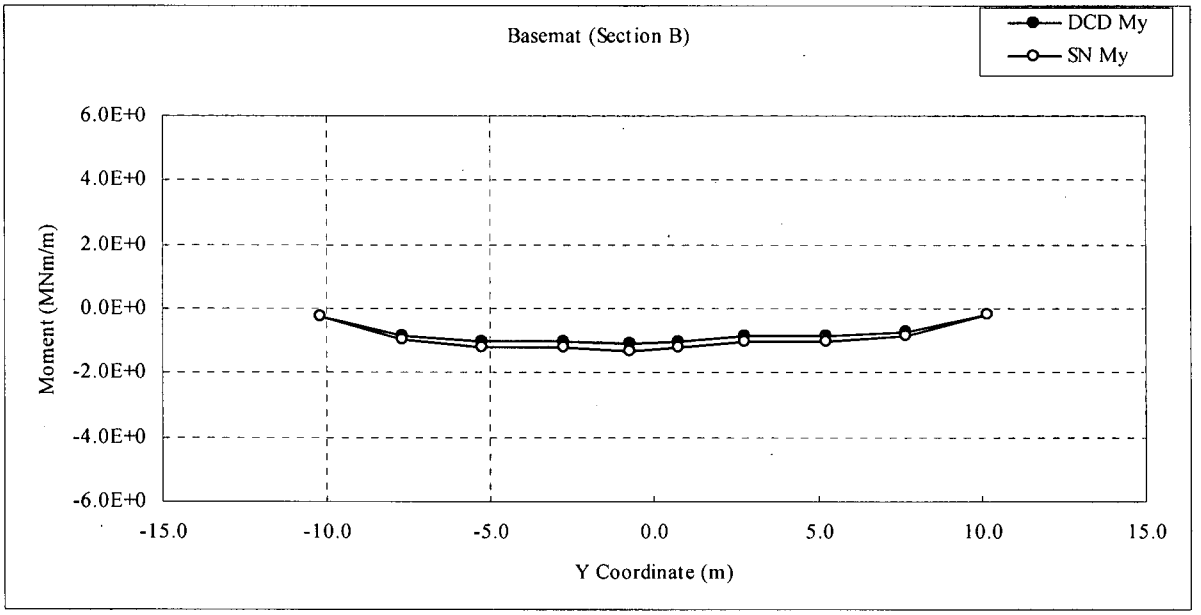
(a) My in E-W Section



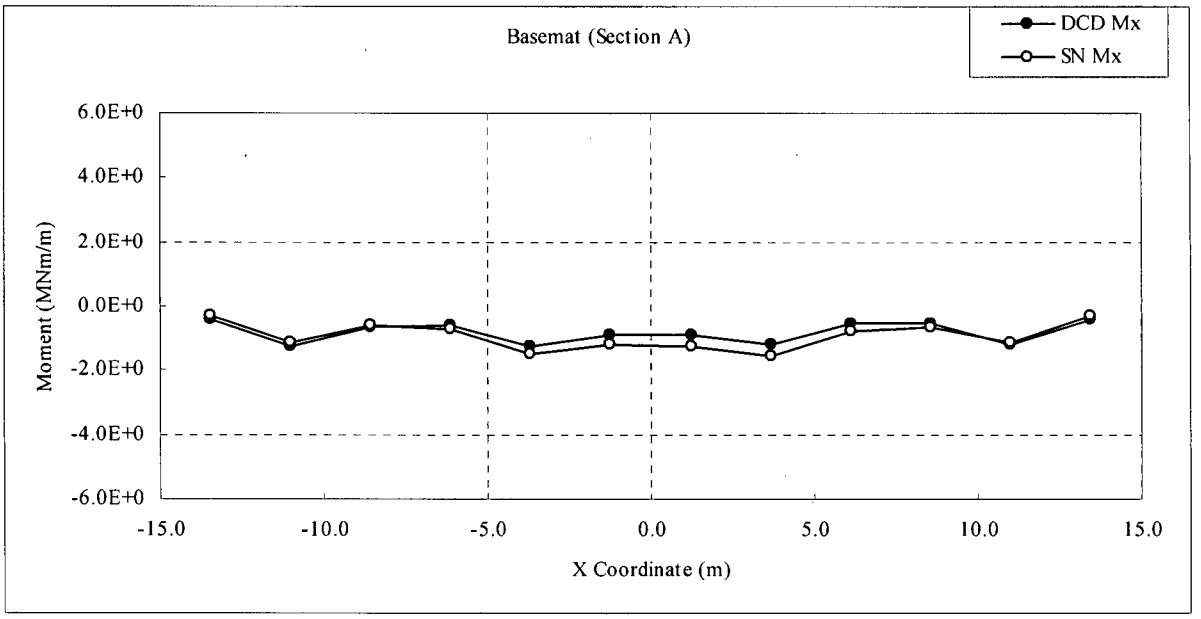
(b) Mx in N-S Section

Figure 3.8-93 (13)-c Comparison of Basemat Sectional Moments (CB, N-S direction)



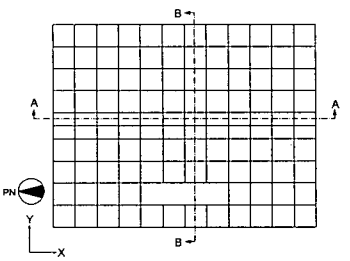


(a) My in E-W Section



(b) Mx in N-S Section

Figure 3.8-93 (13)-d Comparison of Basemat Sectional Moments (CB, S-N direction)



Evaluation for NRC RAI 3.8-93 (3), (7) and (8)

Basemat Design Considering Horizontal Variation of Soil Springs

1. Scope

The original response to NRC RAI 3.8-93 in MFN 06-407 was reviewed by the NRC at the 2nd structural audit in San Jose. It provided the study results based on the "Hard Spot" soil condition under the RPV pedestal area. The NRC requested that other variations such as the inverted type of soil condition (i.e., considering softer soil under the pedestal, "Soft Spot") be added.

This section provides the results of the global model FE analyses concerning the "Soft Spot" soil condition, in addition to the results for "Hard Spot."

2. Analysis condition

Analyses are performed for different soil conditions (non-uniform condition), which are then compared to the DCD design. Analytical conditions are as follows:

- FEM Model: Global FEM Model (DCD Design Model) [Base Case]
- Soil Condition: "Hard Spot", stiff springs are placed under the Pedestal area.
  "Soft Spot", stiff springs are placed peripheral area of pedestal. Four types of soil conditions are considered as shown in Figure 3.8-93 (14) in each Spot condition.
- Load: Dead Load
- Analysis cases: Stiffer area has four types of soil stiffness as shown Table 3.8-93(3) and Figure 3.8-93(14).

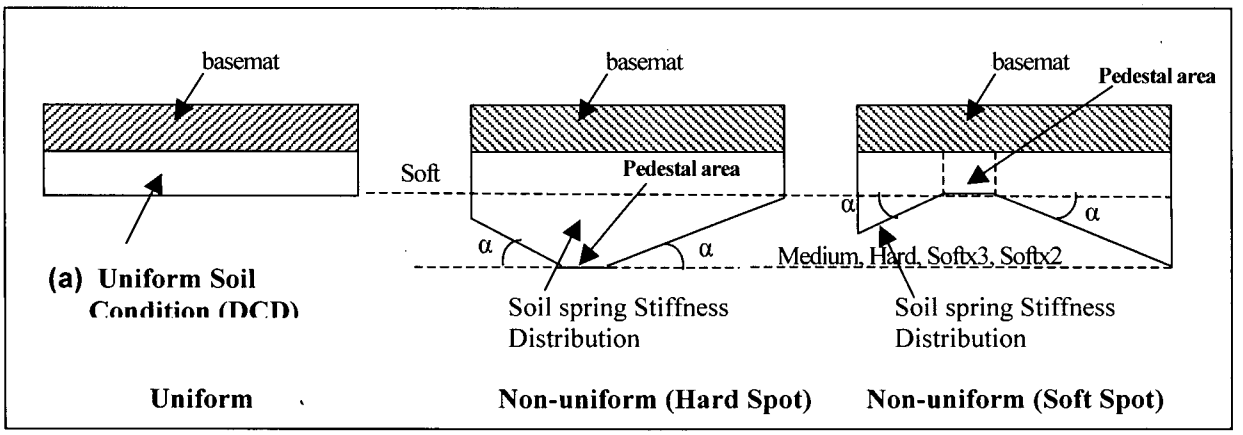


Figure 3.8-93 (14) Soil conditions

Table 3.8-93(3) Analysis Case

Type	No.	Soil Conditions*	
		Center(Inner Pedestal)	Outer(edge of mat)
Hard Spot	H-1	Hard	Soft
	H-2	Medium	
	H-3	Softx3	
	H-4	Softx2	
Soft Spot	S-1	Soft	Hard
	S-2		Medium
	S-3		Softx3
	S-4		Softx2

* See DCD Tier 2 Table 3A.3-1 for site properties. Softx3 and Softx2 have three and two times the soft soil stiffness respectively.

3. Analysis result

Figures 3.8-93(15) and (16) show the basemat deformation and bending moment compared with the DCD design (uniform soil condition), including "Hard Spot" condition. These figures indicate that the bending moment for the Hard Spot condition is smaller or similar to the DCD design since the soil springs are stiffer than the DCD condition (uniform soft soil). However, the "Soft Spot" condition slightly exceeds the DCD condition. Figures 3.8-93(17) through (23) compare the moments at the bottom of the walls. Also in these figures, some of the "Soft Spot" cases show slight differences from the DCD envelope. However, the DCD design envelops the result of the horizontal soil spring variations as long as the ratio of the spring stiffness at the basemat center to that at the basemat edge does not exceed 3. This spring stiffness ratio converts to $\sqrt{3}$ (1.7) for the corresponding shear wave velocity ratio.

4. Conclusion

Figure 3.8-93(24) shows the relative displacement normalized to the basemat displacement at the center position of the RPV. It is found that the "Hard Spot" condition results in a different pattern of relative displacements when compared against the DCD Tier 2 analysis results.

Figure 3.8-93(16)-c indicates that moments for the "Soft x 3" case exceed the base case (DCD) under the "Hard Spot" condition. For the design allowable, slightly less than 3x soft or hard conditions is used. In fact, ACI-336.2R, *Suggested Analysis and Design Procedure for Combined Footings and Mats*, Section 6.9, suggests only using 2x.

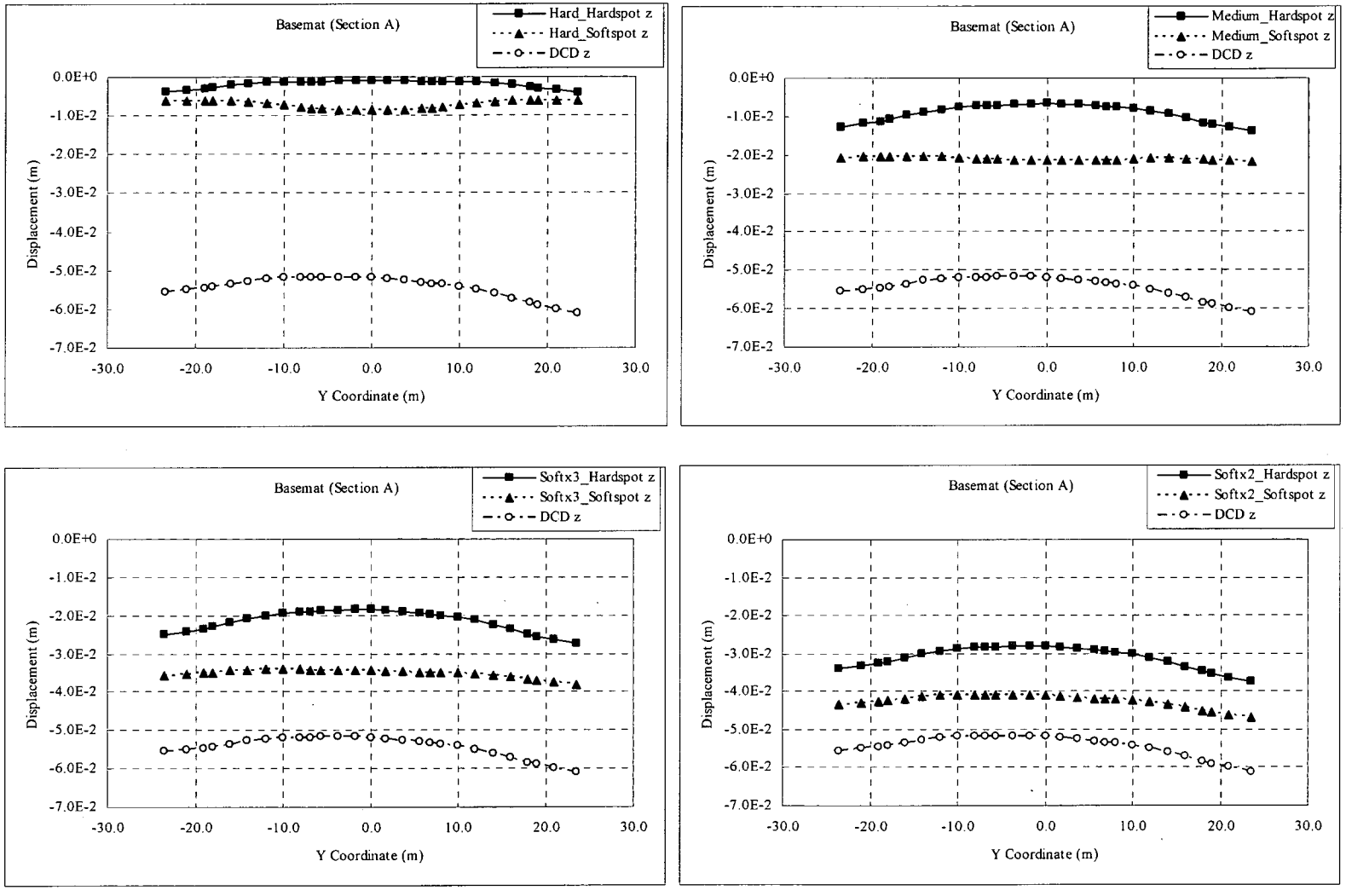


Figure 3.8-93 (15) -a Comparison of Basemat Deformation (E-W Section)

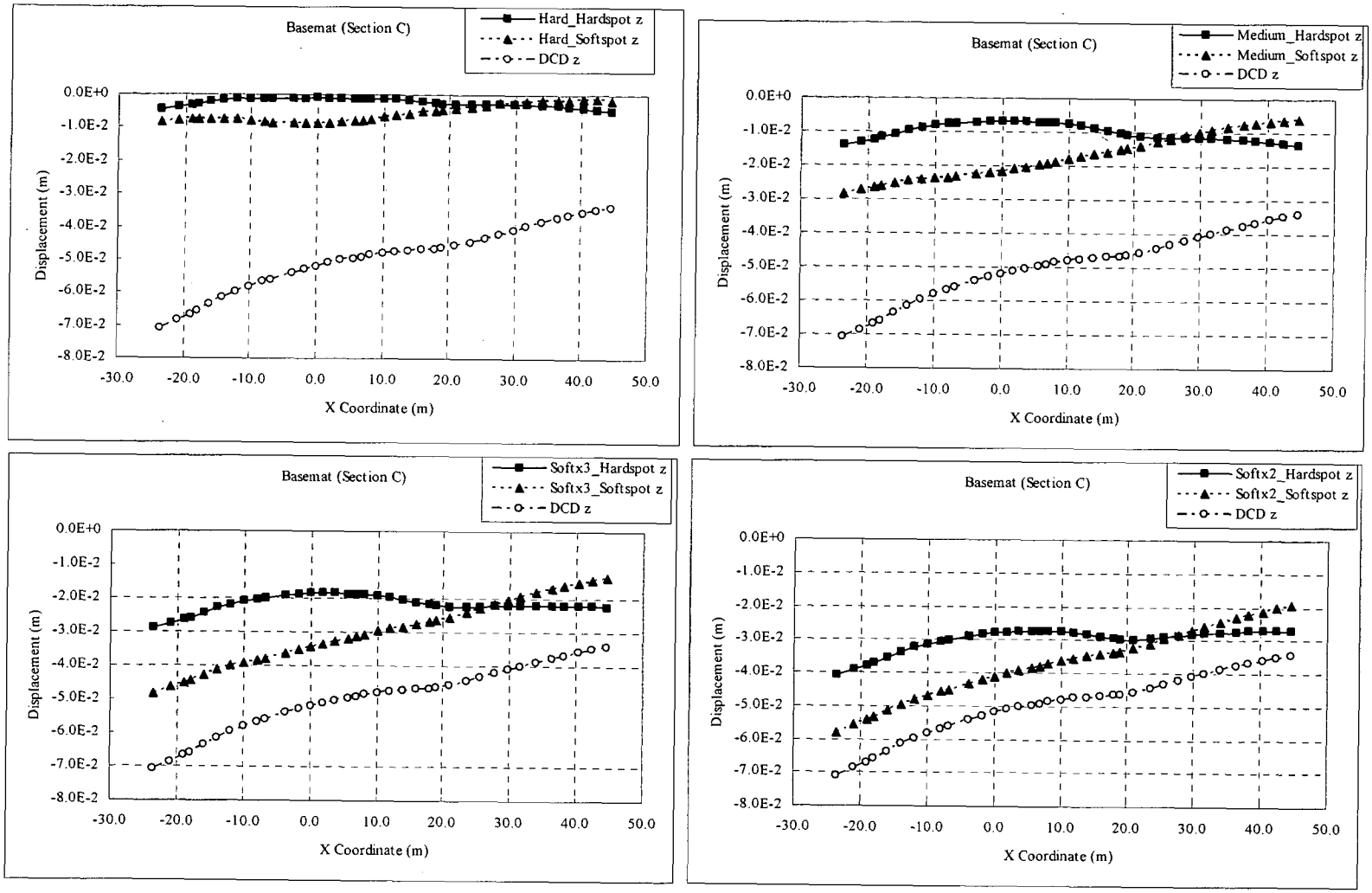
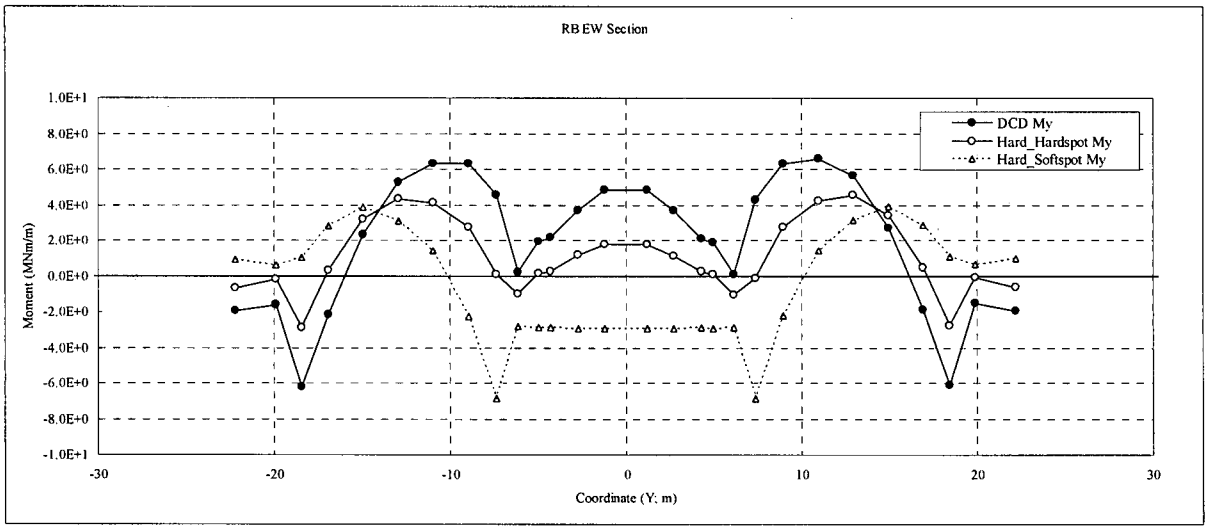
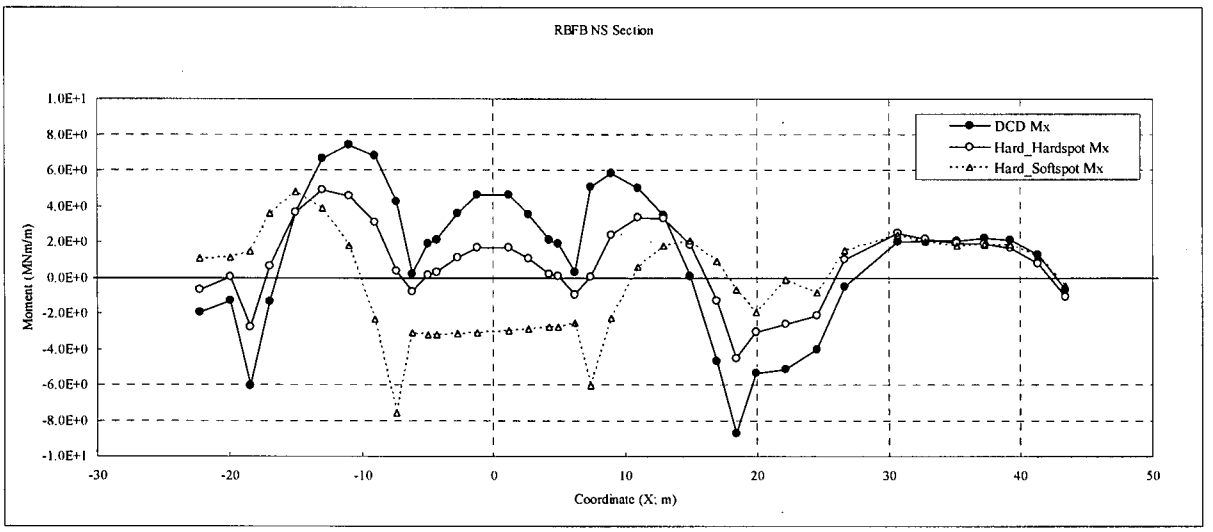


Figure 3.8-93 (15)-b Comparison of Basemat Deformation N-S Section)

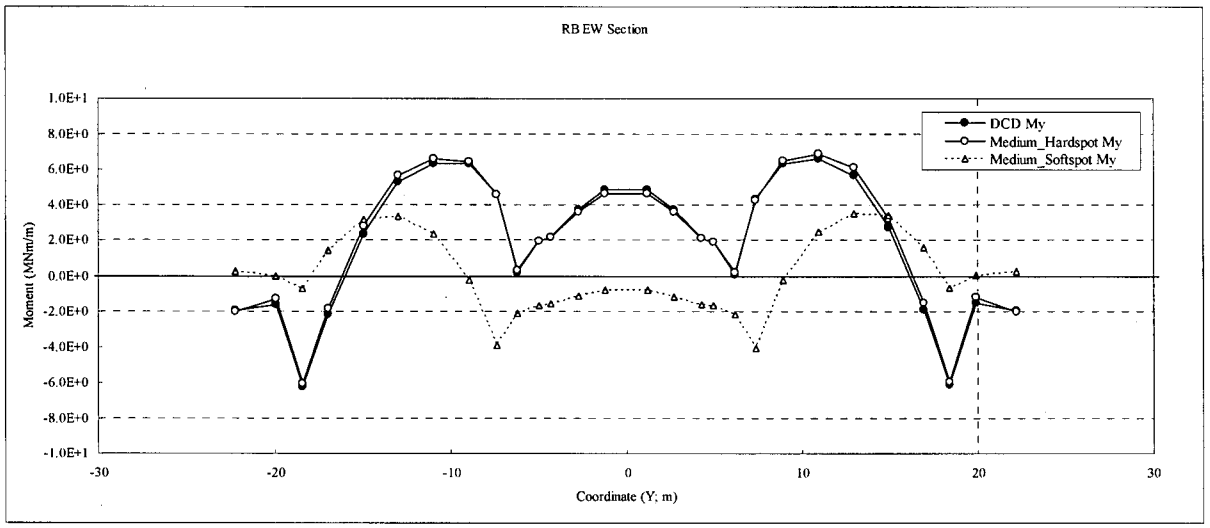


(a) My in E-W Section

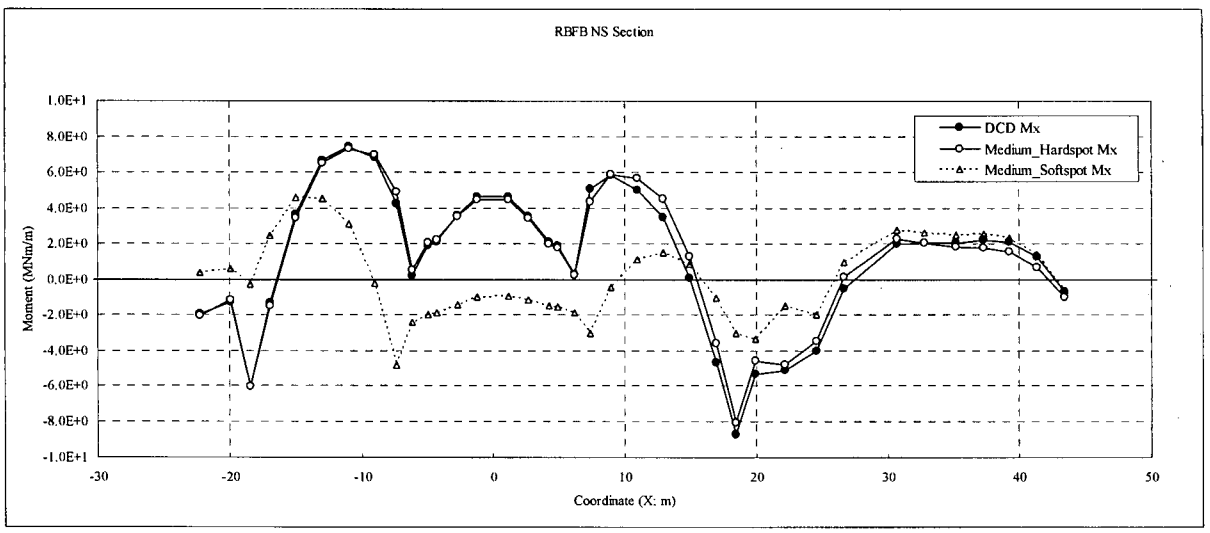


(b) Mx in N-S Section

Figure 3.8-93 (16)-a Comparison of Basemat Sectional Moments (Hard)

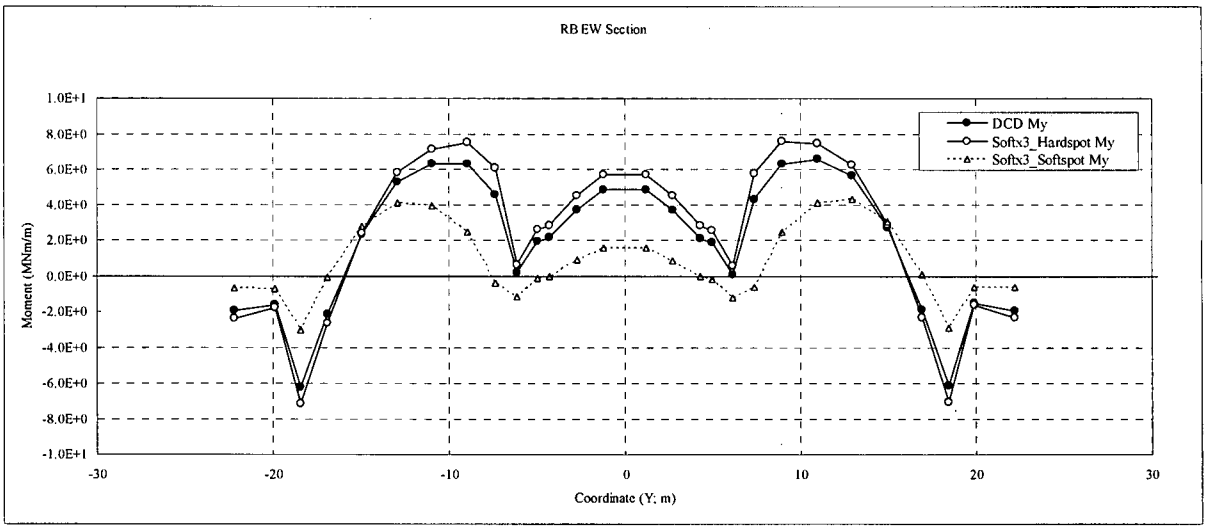


(a) My in E-W Section

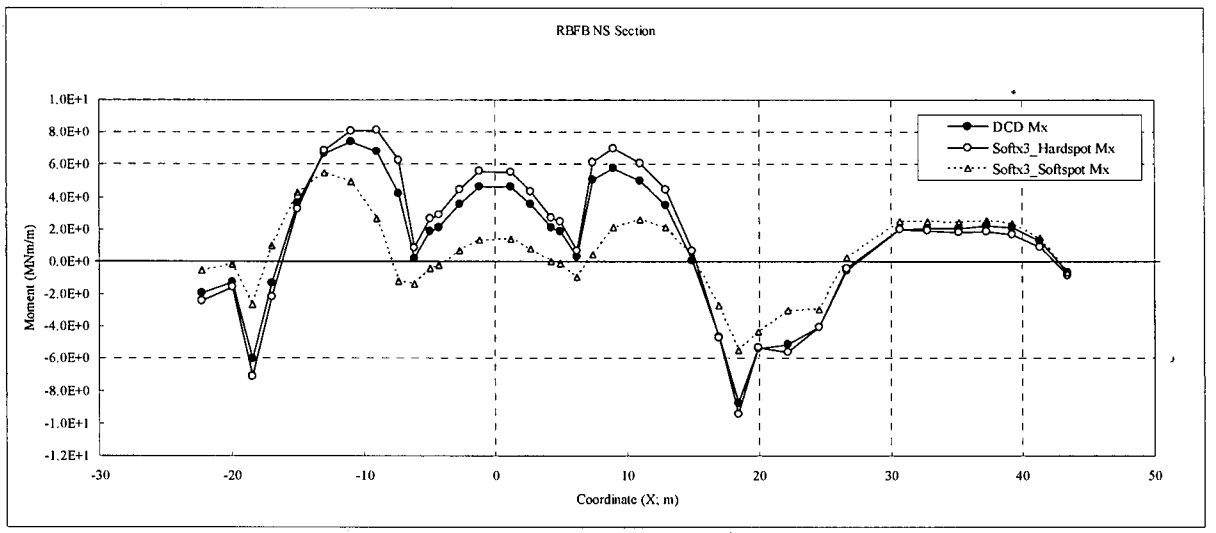


(b) Mx in N-S Section

Figure 3.8-93 (16)-b Comparison of Basemat Sectional Moments (Medium)

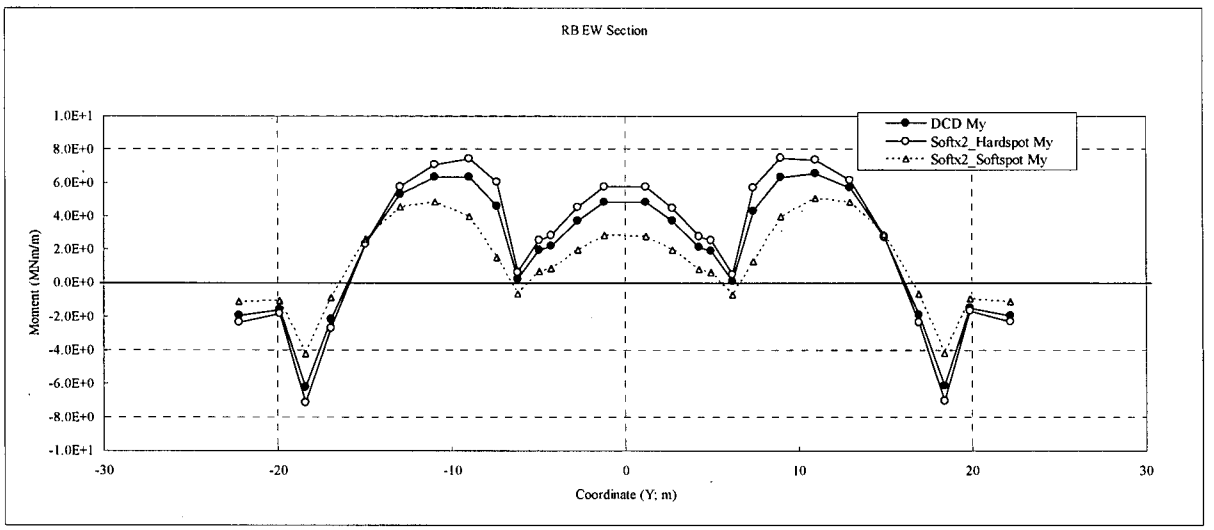


(a) My in E-W Section

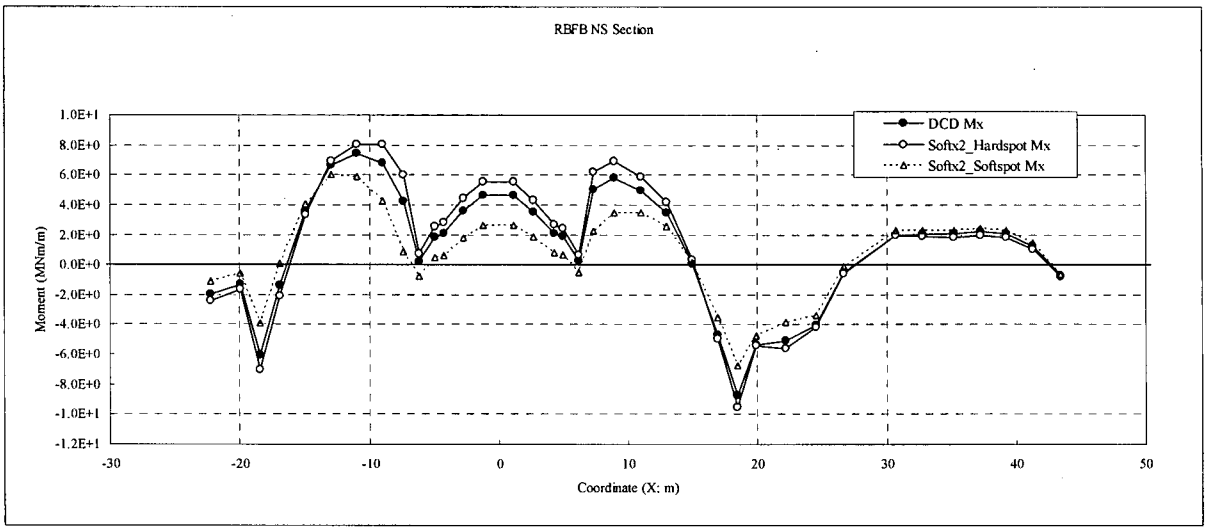


(b) Mx in N-S Section

Figure 3.8-93 (16)-c Comparison of Basemat Sectional Moments (soft x3)



(a) My in E-W Section



(b) Mx in N-S Section

Figure 3.8-93 (16)-d Comparison of Basemat Sectional Moments (soft x2)

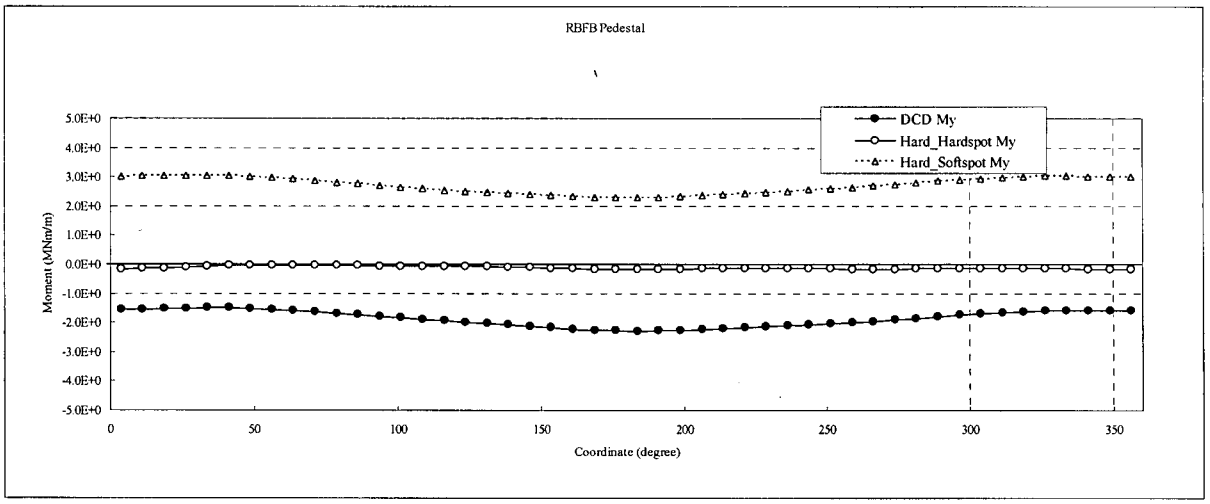


Figure 3.8-93 (17)-a Comparison of Sectional Moments (Pedestal, Hard)

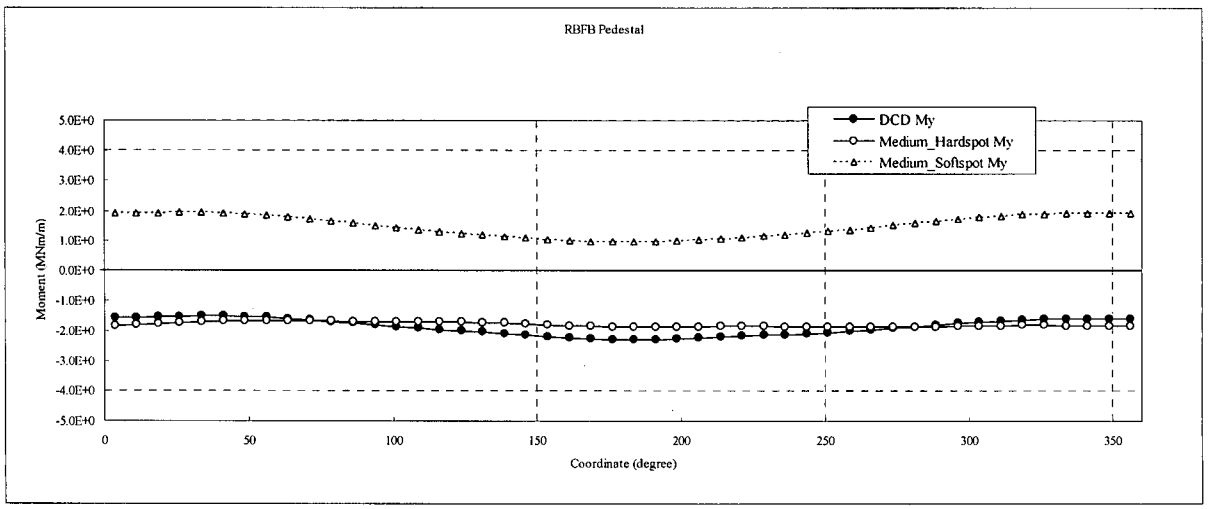


Figure 3.8-93 (17)-b Comparison of Sectional Moments (Pedestal, Medium)

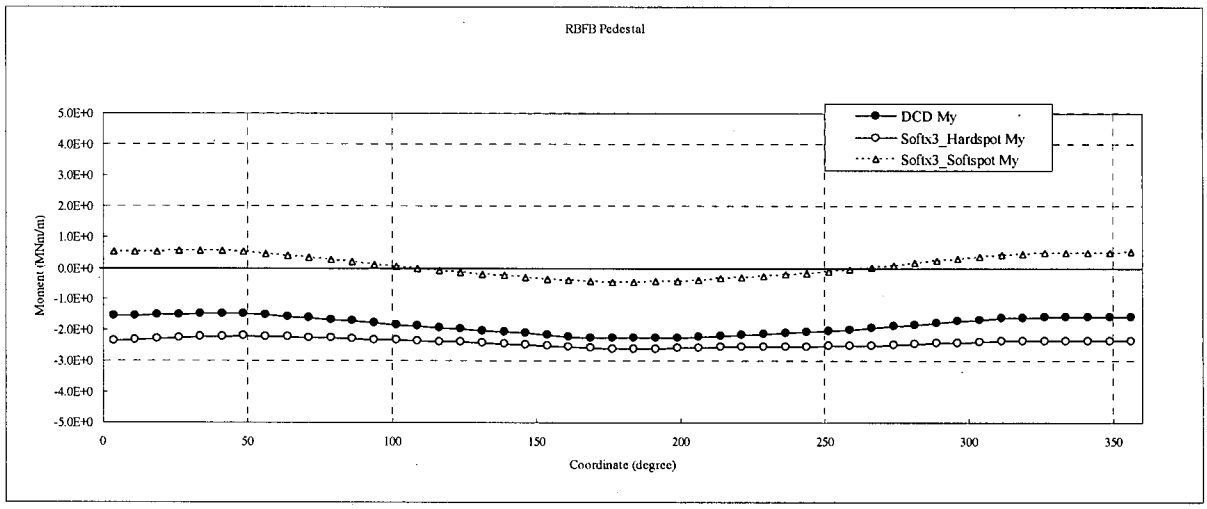


Figure 3.8-93 (17)-c Comparison of Sectional Moments (Pedestal, Soft x3)

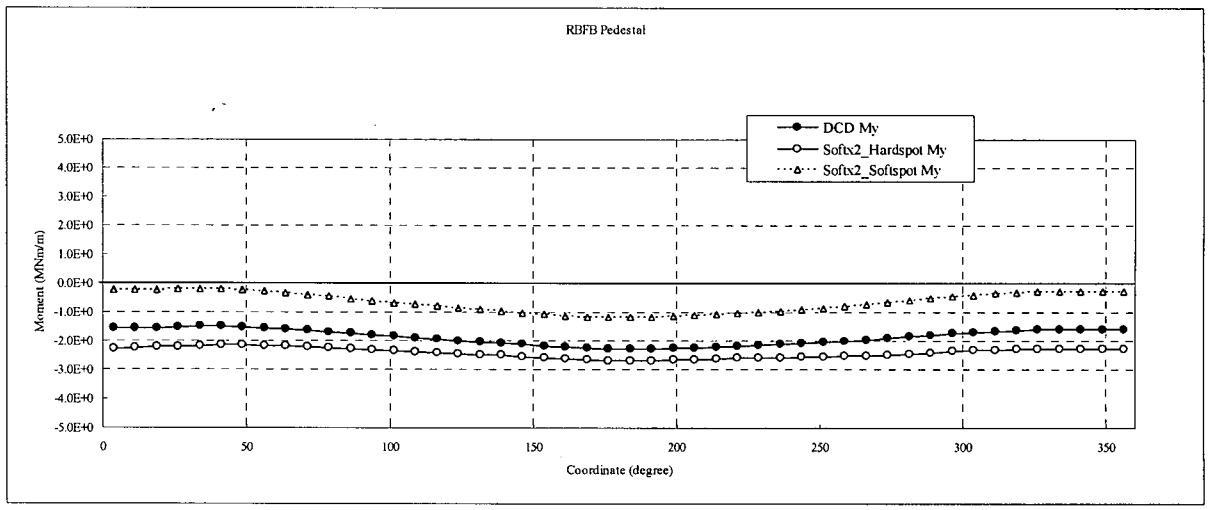


Figure 3.8-93 (17)-d Comparison of Sectional Moments (Pedestal, Soft x2)

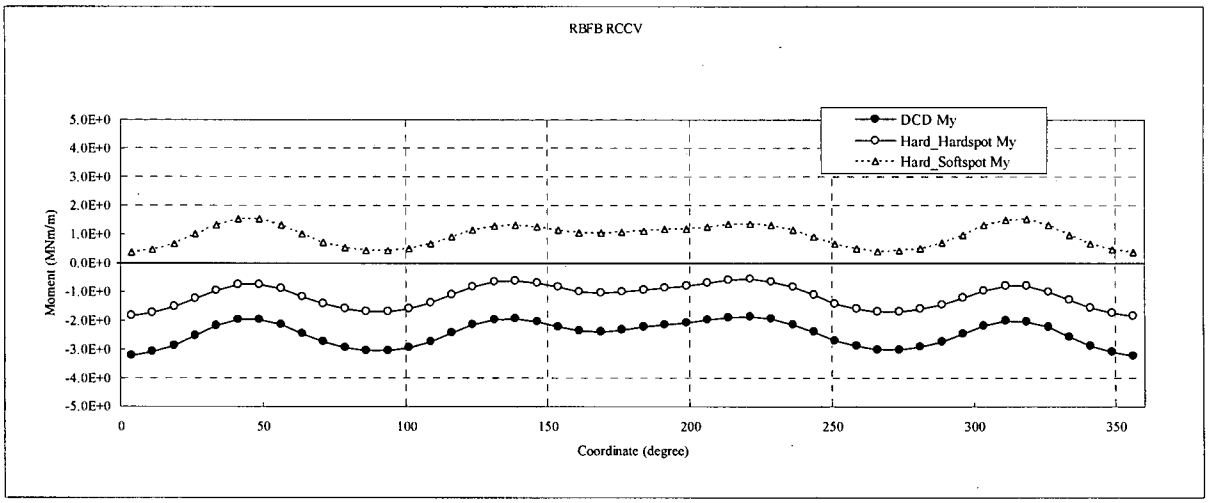


Figure 3.8-93 (18)-a Comparison of Sectional Moments (RCCV bottom, Hard)

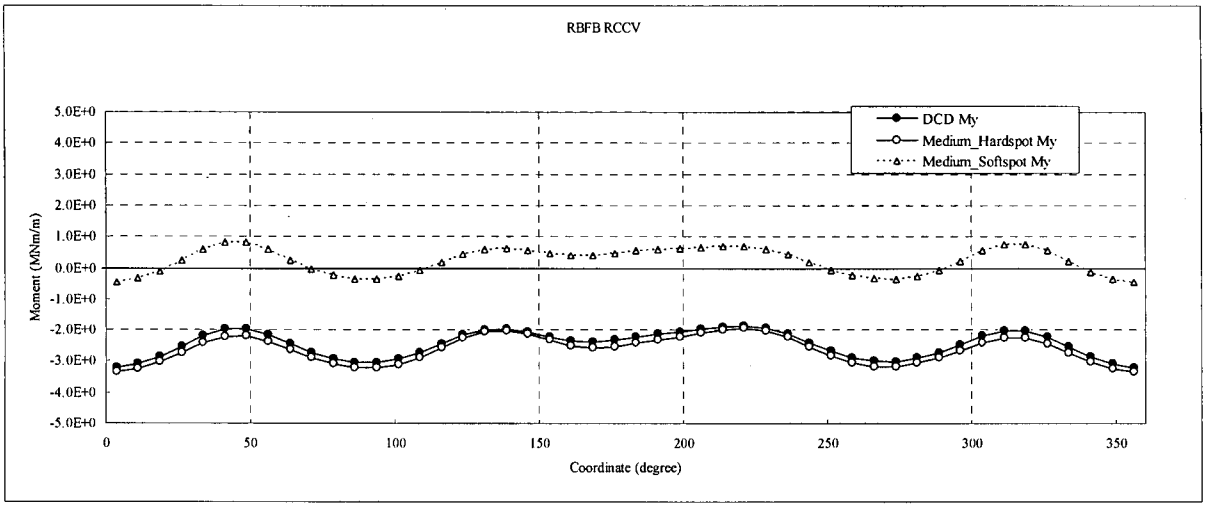


Figure 3.8-93 (18)-b Comparison of Sectional Moments (RCCV bottom, Medium)

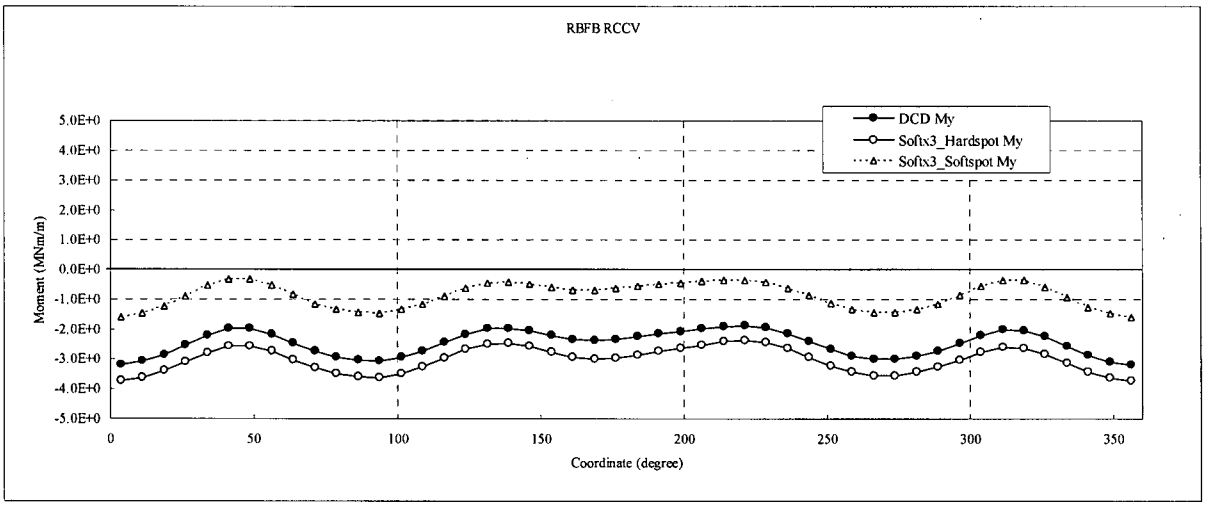


Figure 3.8-93 (18)-c Comparison of Sectional Moments (RCCV bottom, Soft x3)

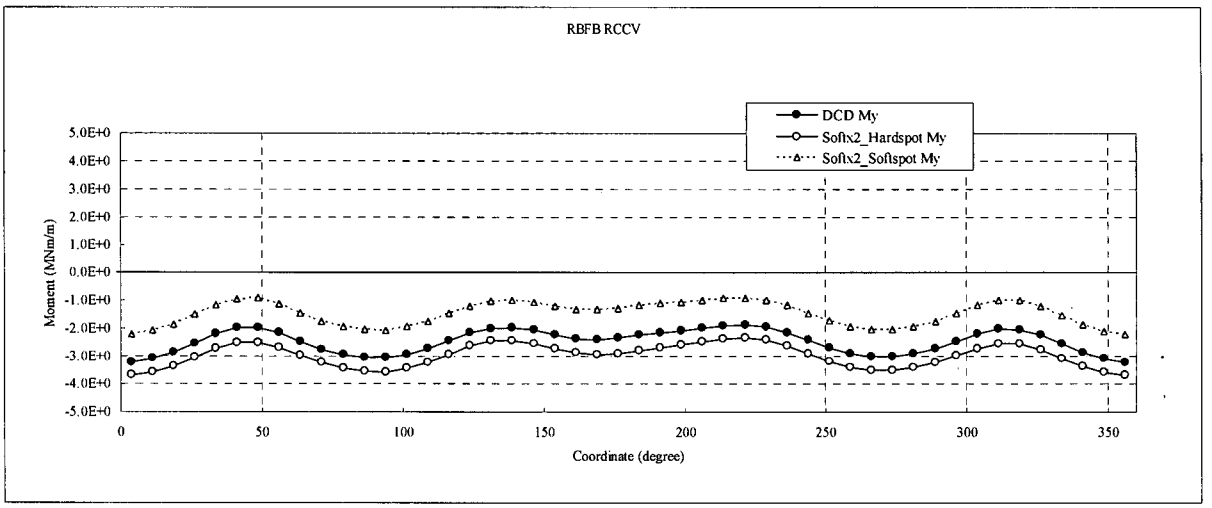


Figure 3.8-93 (18)-d Comparison of Sectional Moments (RCCV bottom, Soft x2)

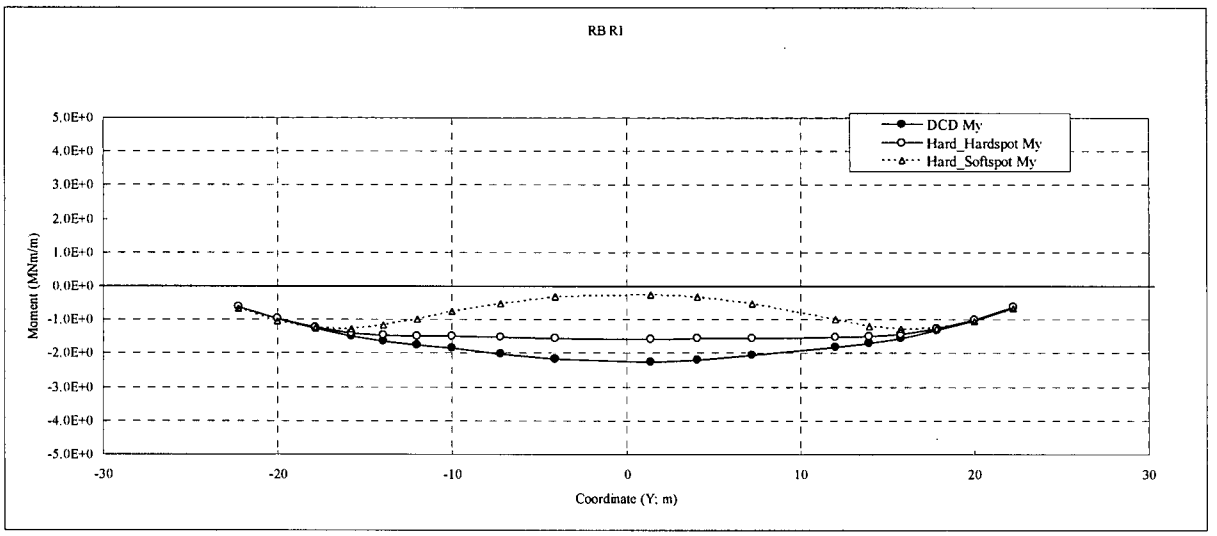


Figure 3.8-93 (19)-a Comparison of Sectional Moments (R1, Hard)

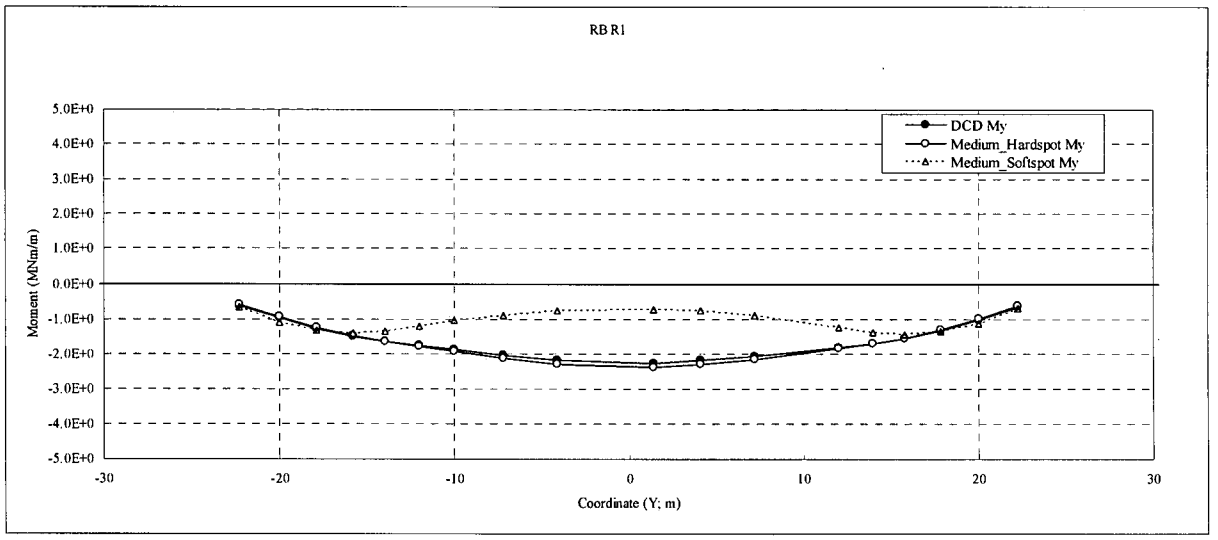


Figure 3.8-93 (19)-b Comparison of Sectional Moments (R1, Medium)

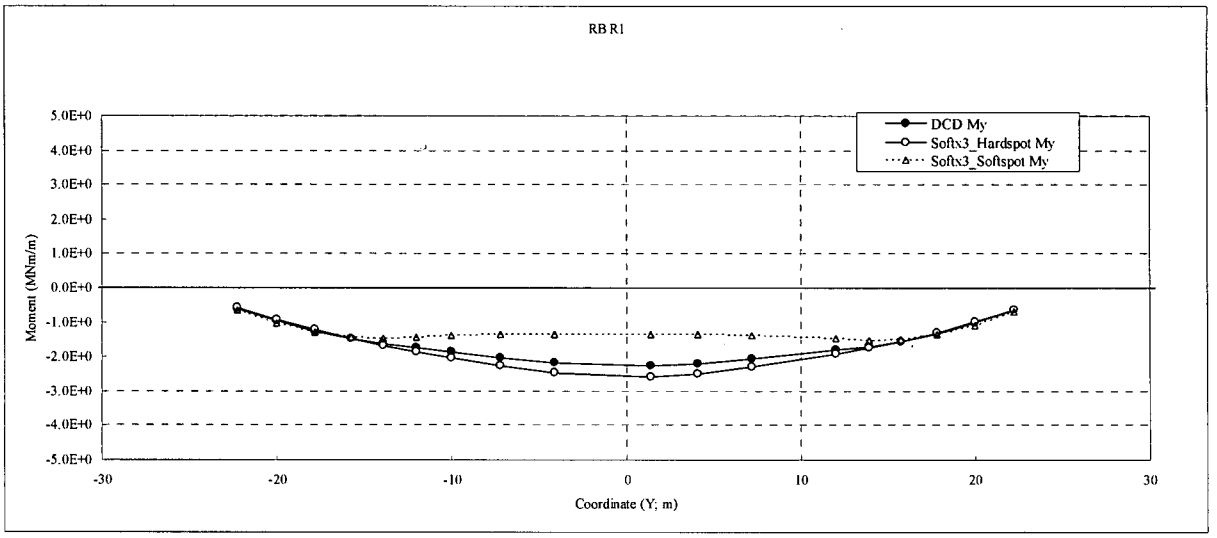


Figure 3.8-93 (19)-c Comparison of Sectional Moments (R1, Soft x3)

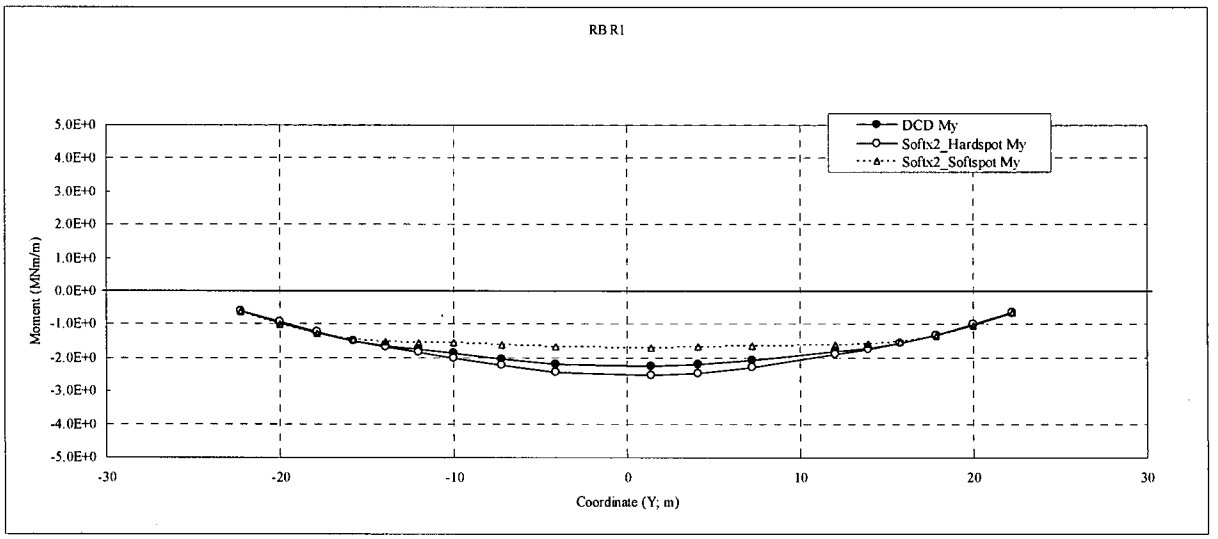


Figure 3.8-93 (19)-d Comparison of Sectional Moments (R1, Soft x2)

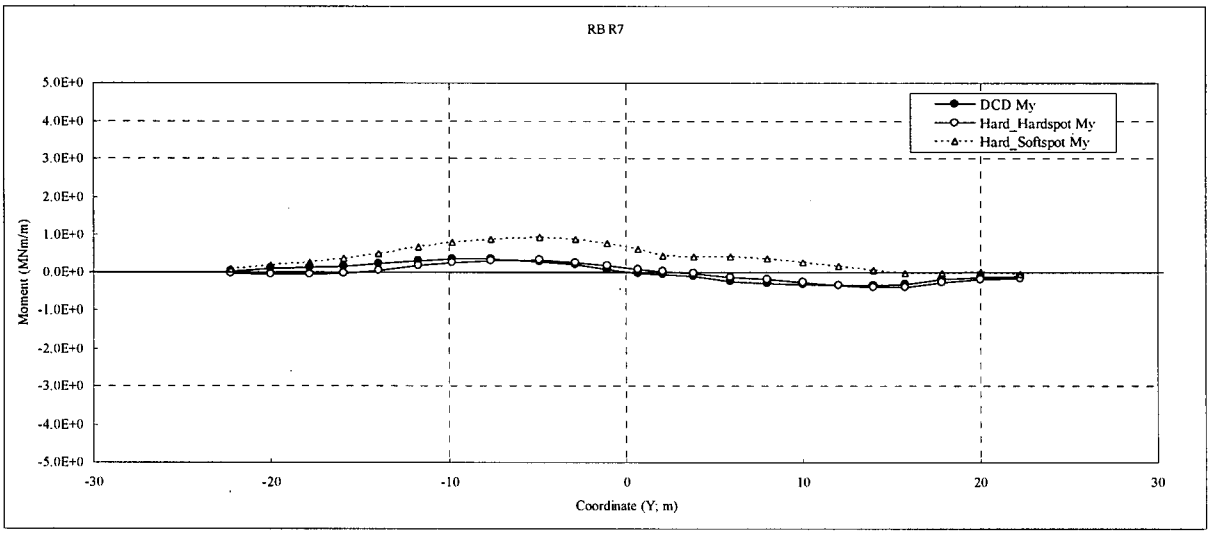


Figure 3.8-93 (20)-a Comparison of Sectional Moments (R7, Hard)

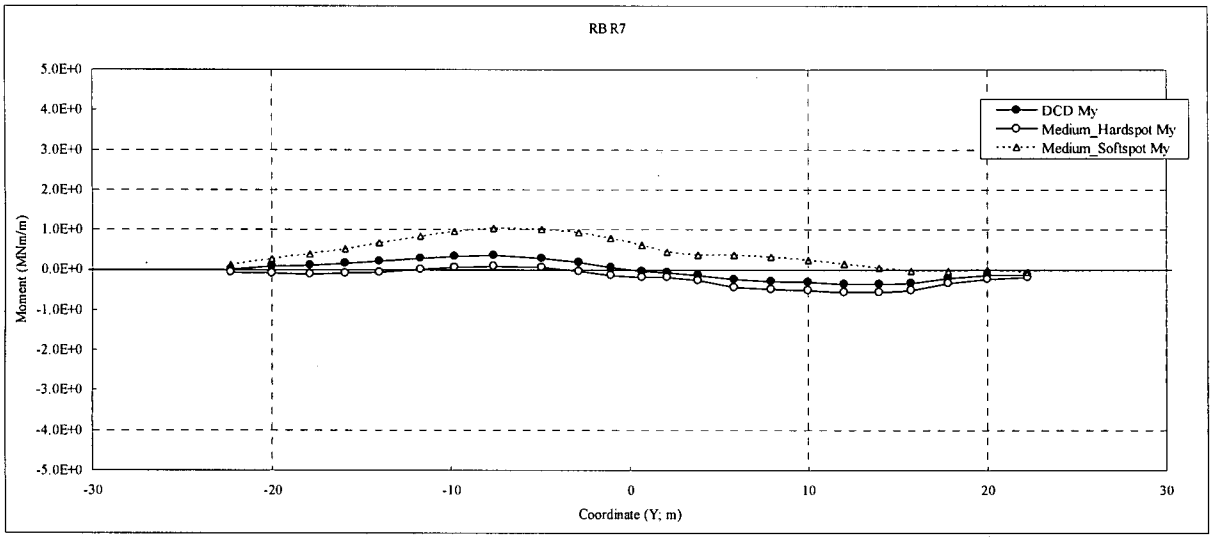


Figure 3.8-93 (20)-b Comparison of Sectional Moments (R7, Medium)

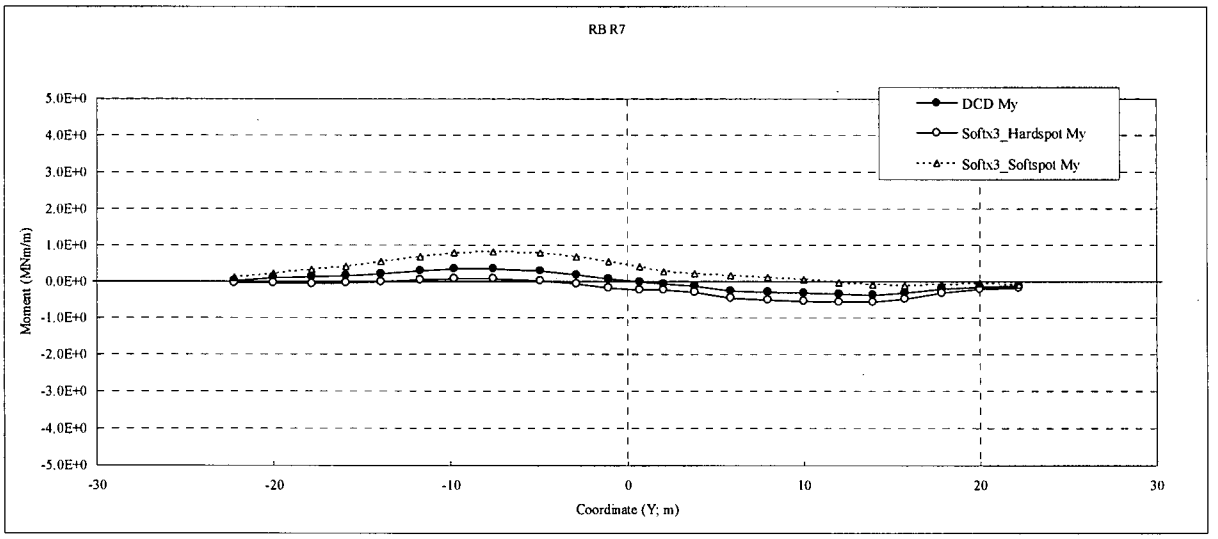


Figure 3.8-93 (20)-c Comparison of Sectional Moments (R7, Soft x3)

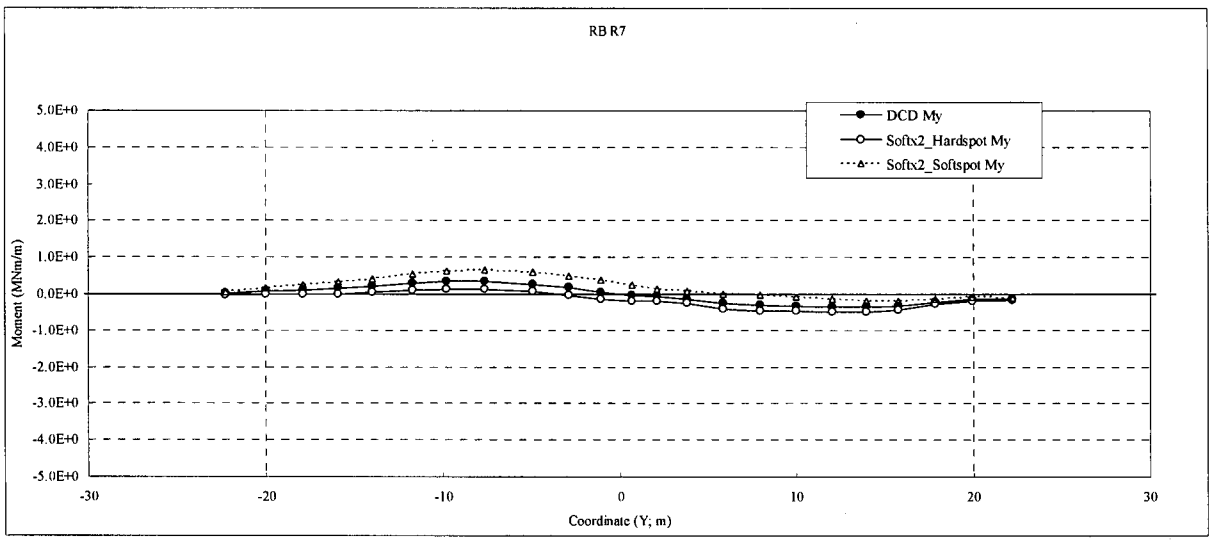


Figure 3.8-93 (20)-d Comparison of Sectional Moments (R7, Soft x2)

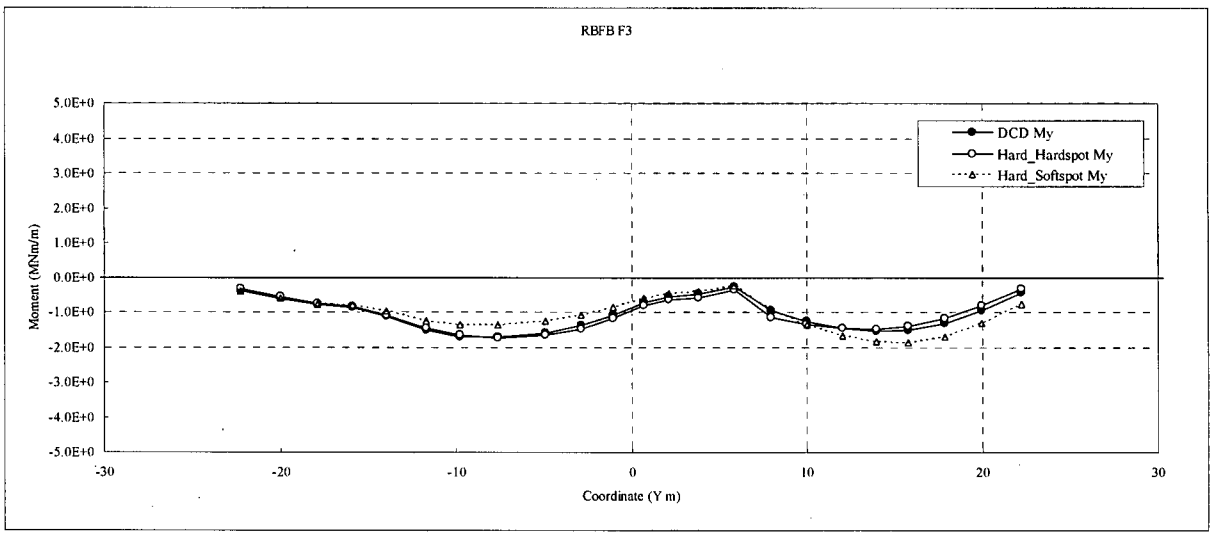


Figure 3.8-93 (21)-a Comparison of Sectional Moments (F3, Hard)

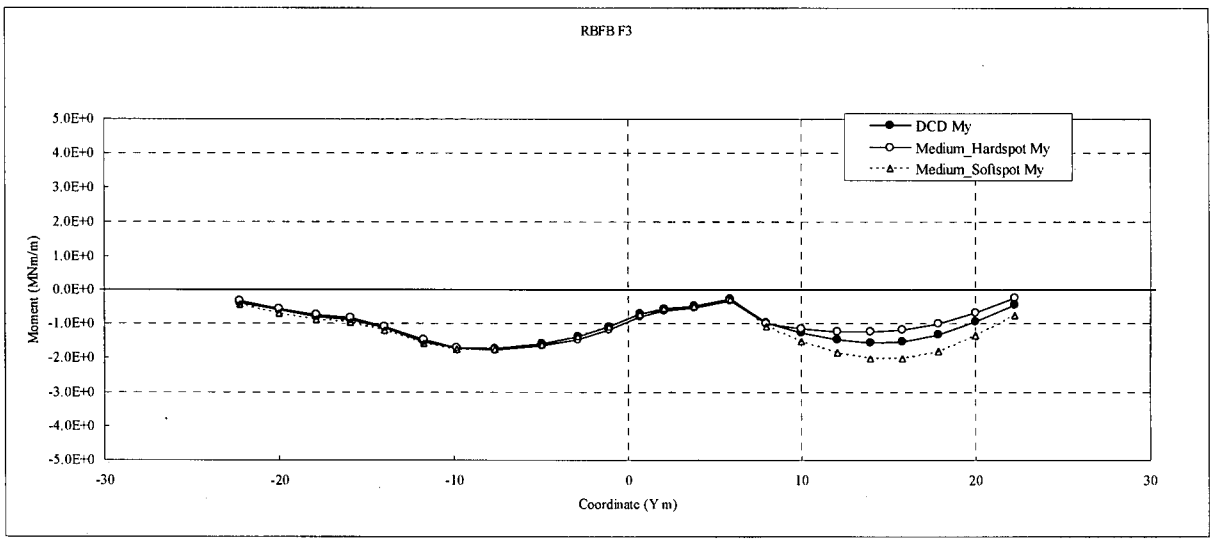


Figure 3.8-93 (21)-b Comparison of Sectional Moments (F3, Medium)

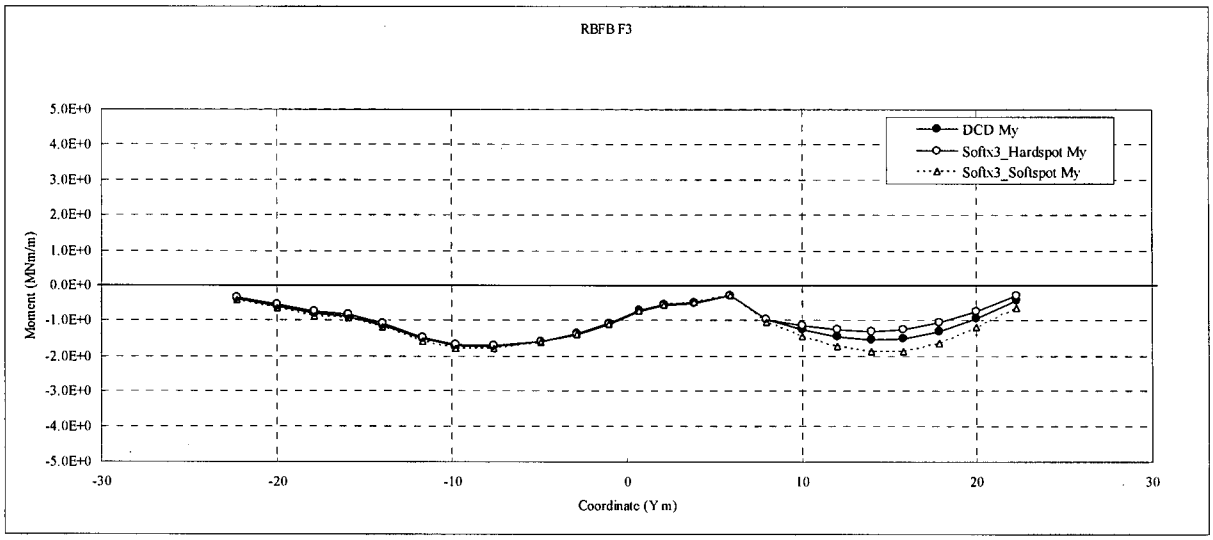


Figure 3.8-93 (21)-c Comparison of Sectional Moments (F3, Soft x3)

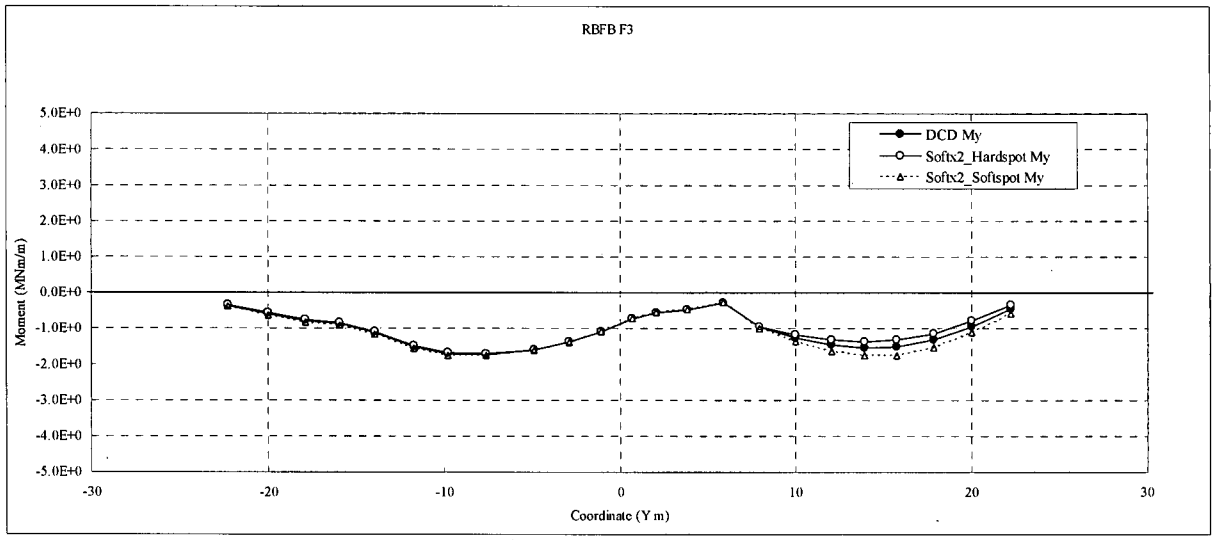


Figure 3.8-93 (21)-d Comparison of Sectional Moments (F3, Soft x2)

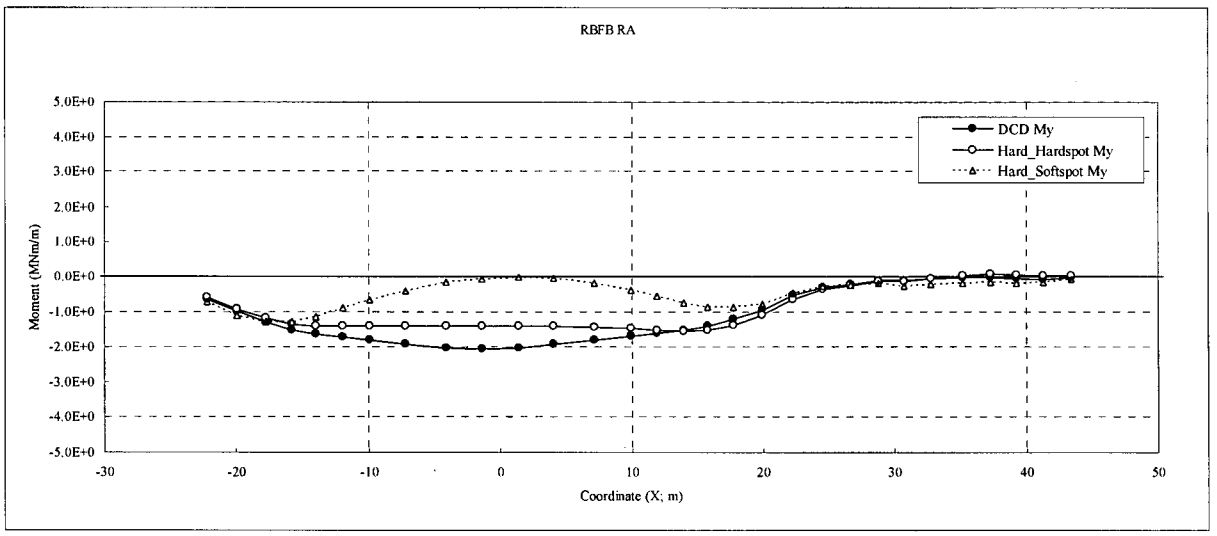


Figure 3.8-93 (22)-a Comparison of Sectional Moments (RA, Hard)

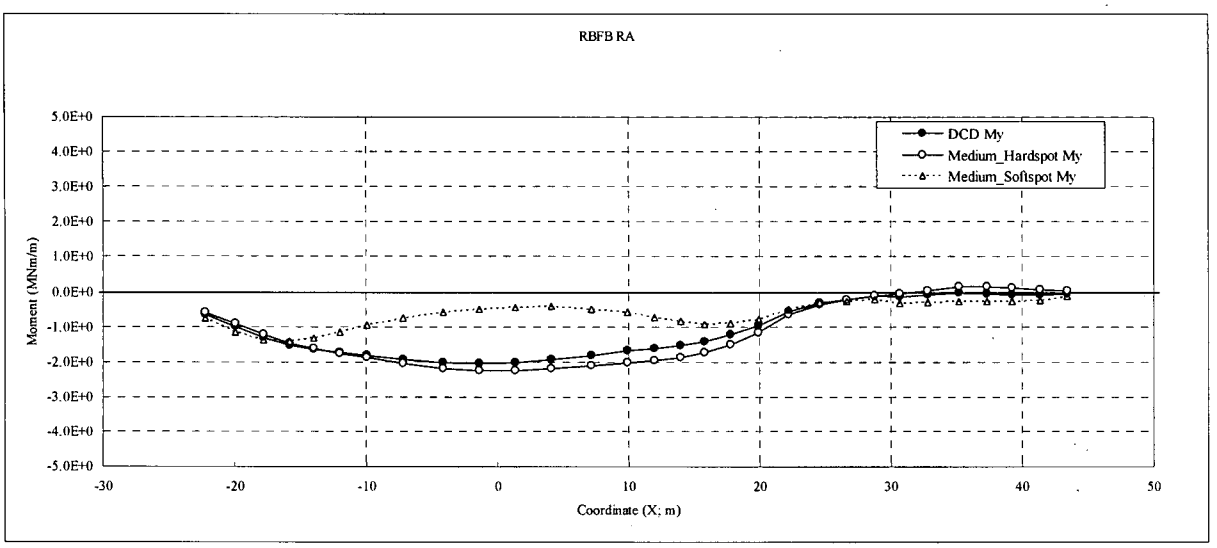


Figure 3.8-93 (22)-b Comparison of Sectional Moments (RA, Medium)

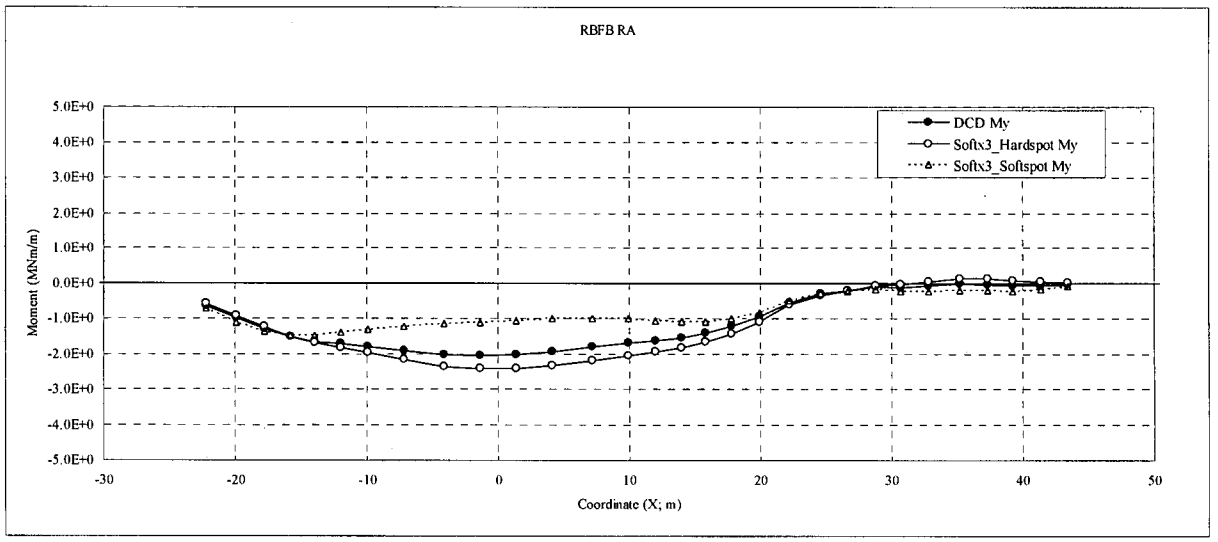


Figure 3.8-93 (22)-c Comparison of Sectional Moments (RA, Soft x3)

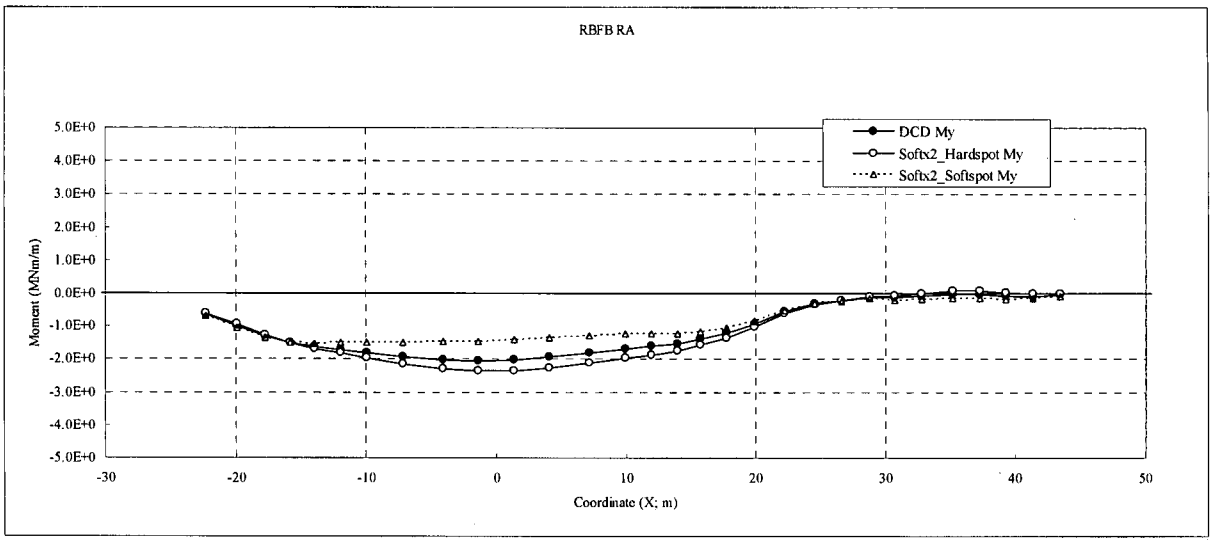


Figure 3.8-93 (22)-d Comparison of Sectional Moments (RA, Soft x2)

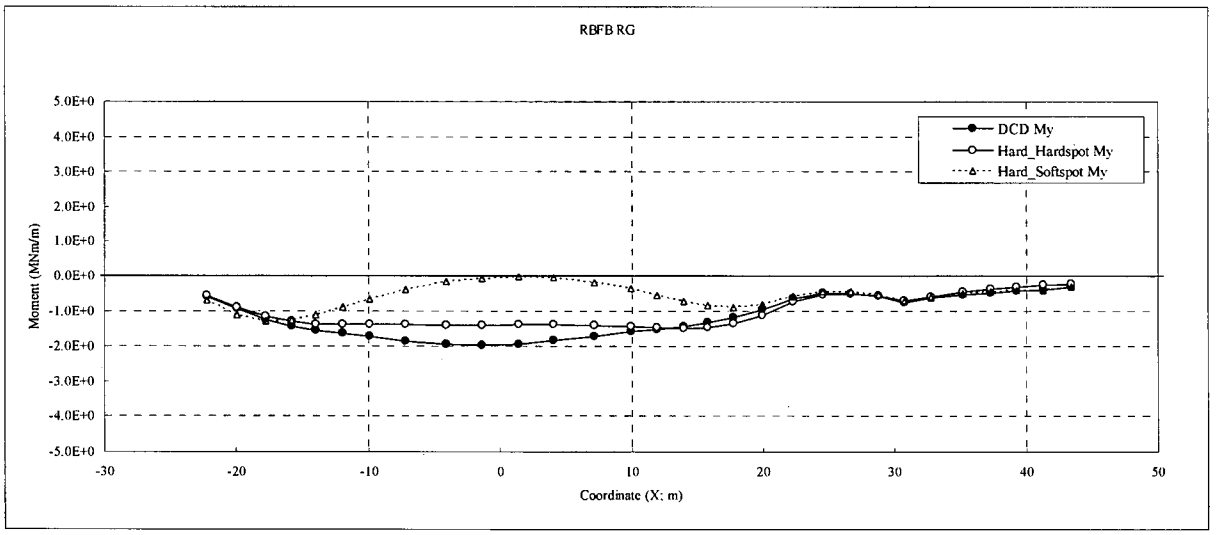


Figure 3.8-93 (23)-a Comparison of Sectional Moments (RG, Hard)

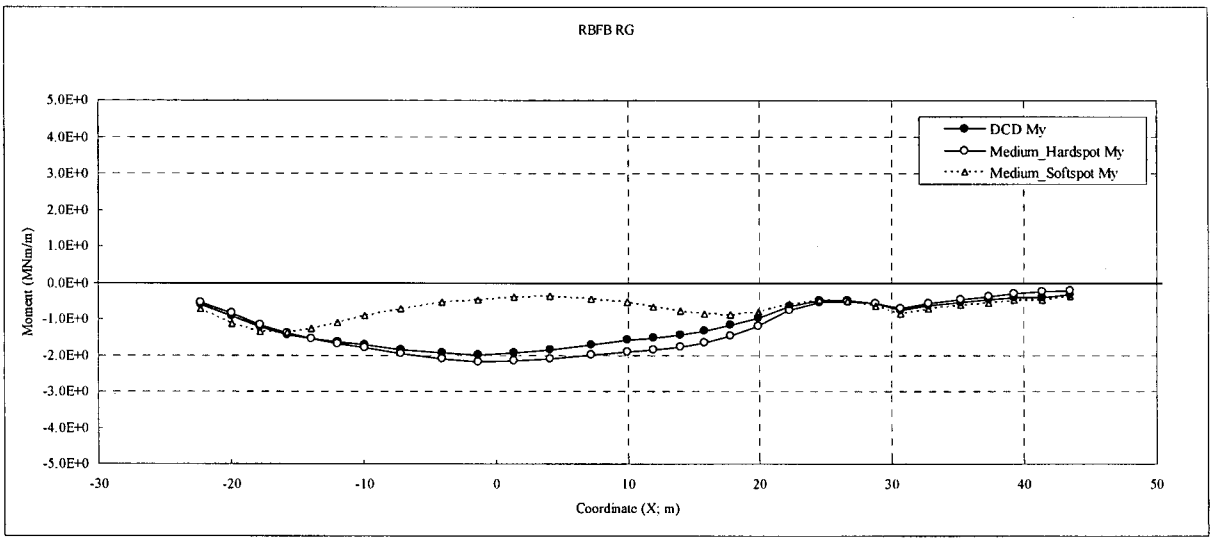


Figure 3.8-93 (23)-b Comparison of Sectional Moments (RG, Medium)

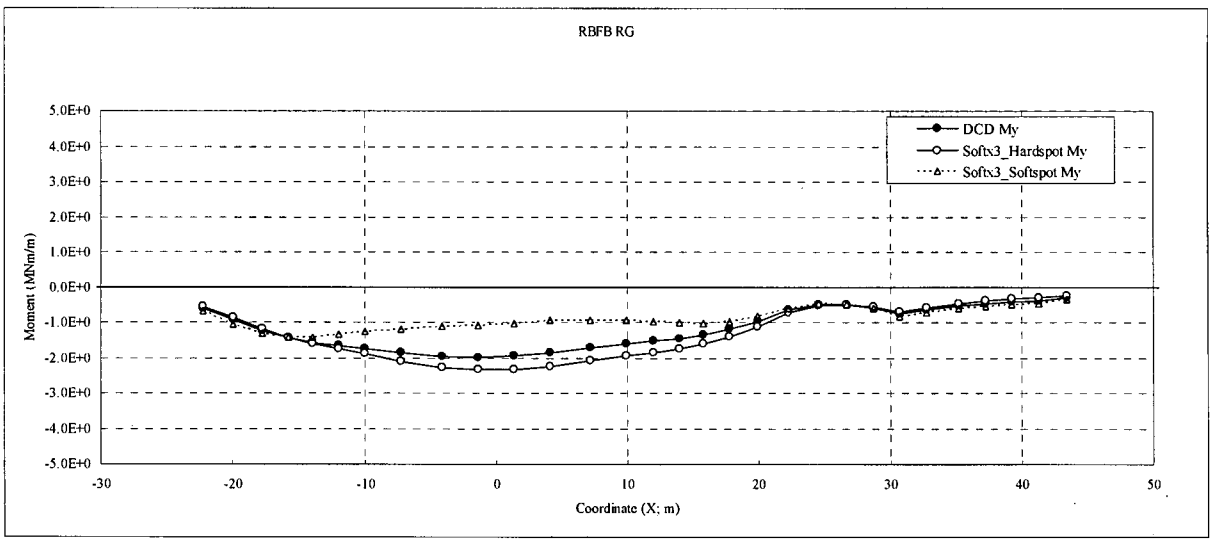


Figure 3.8-93 (23)-c Comparison of Sectional Moments (RG, Soft x3)

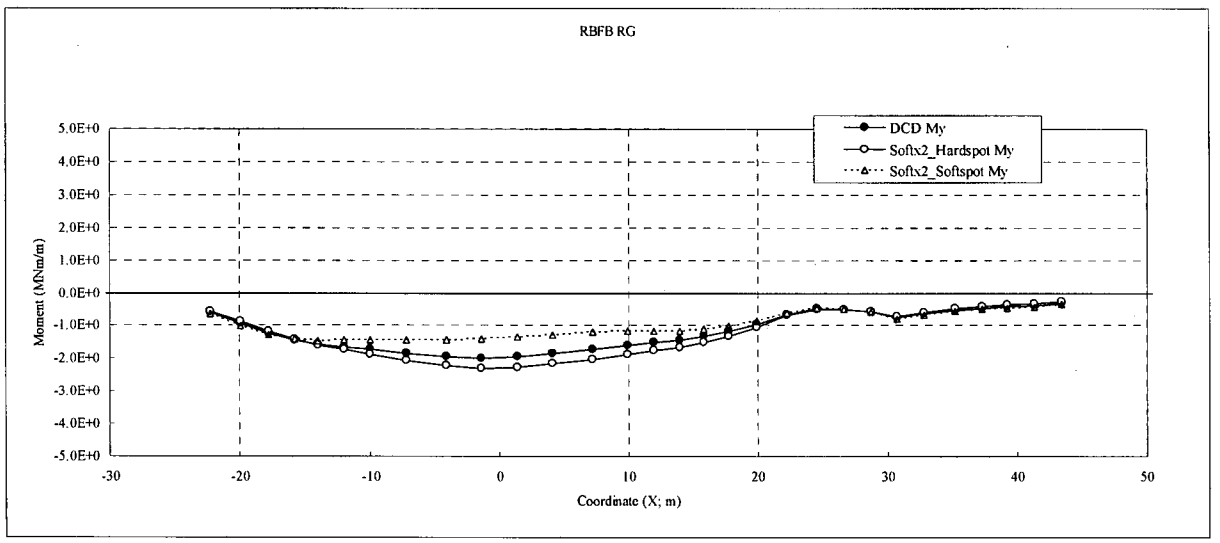


Figure 3.8-93 (23)-d Comparison of Sectional Moments (RG, Soft x2)

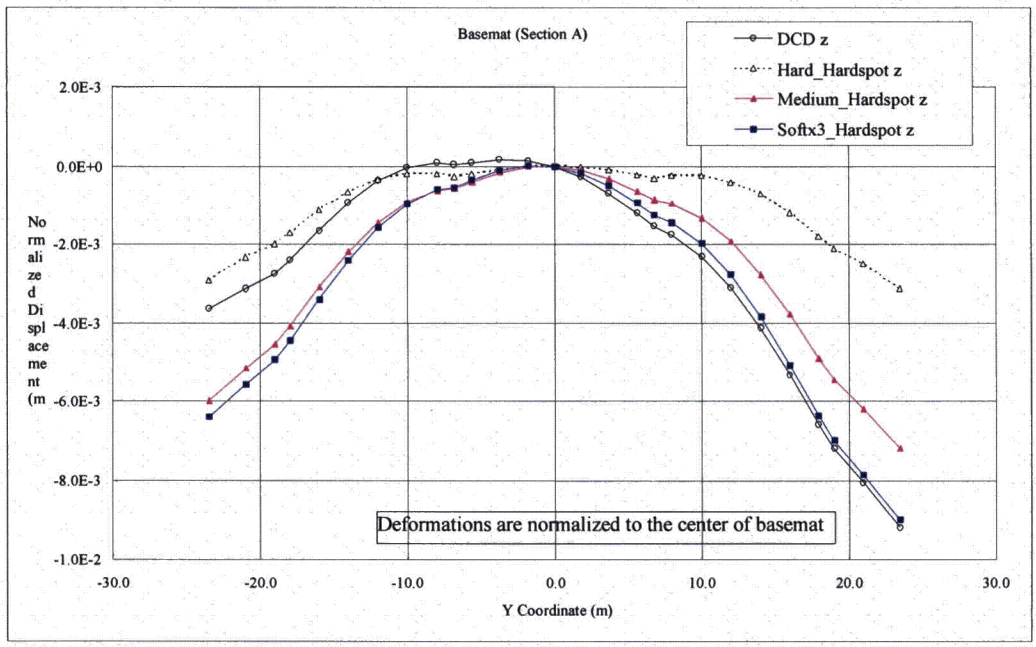


Figure 3.8-93 (24)-a Comparison of Normalized Basemat Displacement (E-W Section)

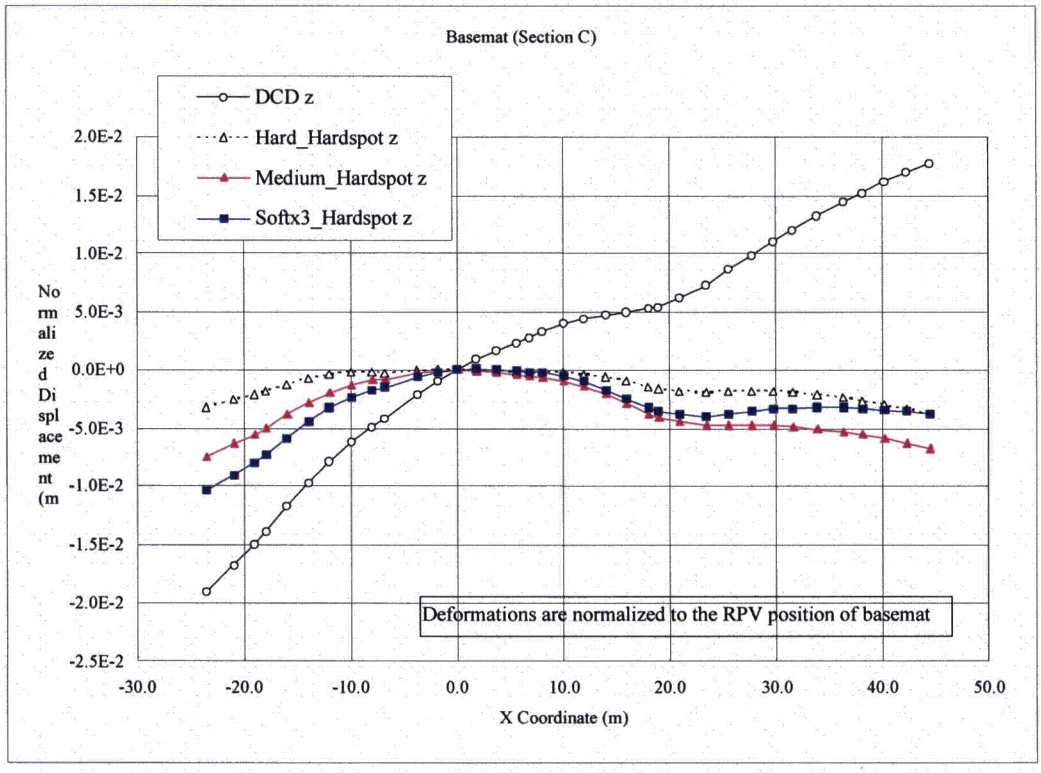


Figure 3.8-93 (24)-b Comparison of Normalized Basemat Displacement (N-S Section)

Evaluation for NRC RAI 3.8-93 (5)

Effect of Basemat Construction Sequence

1. Scope

This study is performed to evaluate the effect of the basemat concrete pour sequence on the basemat stress.

Moments at different locations in the basemat during construction are calculated by FE analyses with variations of construction sequences and soil conditions.

2. Analysis Method

2.1 Construction Sequence

Based on the construction techniques and experience of a recent ABWR plant basemat, the RBFB basemat is divided into 7 concrete pour zones (see Figure 3.8-93(25).)

At the first stage of construction, 0.9 m thick concrete is poured. This thickness is sufficient to cover the basemat bottom layer of rebars.

Then, 3.1 m thick concrete is sequentially poured on the 0.9 m thick concrete. The concrete pour sequences are shown in Table 3.8-93(4). Three cases are considered in this study. Among these cases, Case 3 is selected as an example of concrete poured randomly.

2.2 Soil Condition

The following three conditions are considered:

- Uniform Soft Soil
- Hard Spot: Hard (stiffness is three times the Soft soil stiffness) below the RPV Pedestal region and Soft condition at the edge of basemat
- Soft Spot: Soft condition below the RPV Pedestal region and Hard (stiffness being three times that of the Soft soil) at the edge of basemat

2.3 Analysis Method

Analyses are performed using the basemat FE model, which is extracted from the RBFB global FE model.

Analysis procedure is as follows:

Step 1: The entire basemat is modeled with 0.9 m thick concrete elements

Step 2: Weight of 3.1 m thick concrete and construction live load of 4.8 kN/m^2 (100 psf) are applied to the elements located in the region where concrete is poured as the first stage.

Step 3: The 0.9m thick elements that were poured in Step 1are increased to 4.0 m. Then, 3.1 m thick concrete and live load are applied to the elements located in the other 0.9m region. This is the second stage.

Step 3 is repeated in similar manner until the basemat concrete pour is completed.

3. Analysis Results

Figures 3.8-93(26) through (29) compare the moments at the final stage of concrete pour and at three sections shown in Figure 3.8-93(25). The design bending moment envelope due to the dead load obtained by the RBFB global FE model analysis are also included in the figures for comparison.

As shown in the figures, moment differences between the sequences considered are negligibly small in comparison with the design moments due to dead load during Normal Operation considered in the basemat design. In addition, the effects of varying soil conditions are not controlling.

Figures 3.8-93(30) through (32) show distributions of the principal tensile stresses generated in the 0.9 m thick concrete slab. The maximum principal tensile stress is summarized in Table 3.8-93(5) for each soil condition and construction sequence. The tensile stress generated by the concrete pour is less than the tensile strength of concrete, which is $0.1f_c' = 2.76\,\text{MPa}$.

Therefore, it can be concluded that:

- The basemat construction sequence has no effect on the basemat design, and
- Significant cracking will not be generated in the basemat during construction.

Table 3.8-93(4) Assumed Sequences of Basemat Concrete Pour

Case	Stage	Sequence of Concrete Pour*							Element Thickness (m)						
		Zone							Zone						
		1	2	3	4	5	6	7	1	2	3	4	5	6	7
1	1	P							0.9	0.9	0.9	0.9	0.9	0.9	0.9
	2	H	P						4.0	0.9	0.9	0.9	0.9	0.9	0.9
	3	H	H	P					4.0	4.0	0.9	0.9	0.9	0.9	0.9
	4	H	H	H	P				4.0	4.0	4.0	0.9	0.9	0.9	0.9
	5	H	H	H	H	P			4.0	4.0	4.0	4.0	0.9	0.9	0.9
	6	H	H	H	H	H	P		4.0	4.0	4.0	4.0	4.0	0.9	0.9
	7	H	H	H	H	H	H	P	4.0	4.0	4.0	4.0	4.0	4.0	0.9
2	1							P	0.9	0.9	0.9	0.9	0.9	0.9	0.9
	2						P	H	0.9	0.9	0.9	0.9	0.9	0.9	4.0
	3					P	H	H	0.9	0.9	0.9	0.9	0.9	4.0	4.0
	4				P	H	H	H	0.9	0.9	0.9	0.9	4.0	4.0	4.0
	5			P	H	H	H	H	0.9	0.9	0.9	4.0	4.0	4.0	4.0
	6		P	H	H	H	H	H	0.9	0.9	4.0	4.0	4.0	4.0	4.0
	7	P	H	H	H	H	H	H	0.9	4.0	4.0	4.0	4.0	4.0	4.0
3	1	P							0.9	0.9	0.9	0.9	0.9	0.9	0.9
	2	H	P						4.0	0.9	0.9	0.9	0.9	0.9	0.9
	3	H	H		P				4.0	4.0	0.9	0.9	0.9	0.9	0.9
	4	H	H		H		P		4.0	4.0	0.9	4.0	0.9	0.9	0.9
	5	H	H		H		H	P	4.0	4.0	0.9	4.0	0.9	4.0	0.9
	6	H	H		H	P	H	H	4.0	4.0	0.9	4.0	0.9	4.0	4.0
	7	H	H	P	H	H	H	H	4.0	4.0	0.9	4.0	4.0	4.0	4.0

Note *: "P" indicates the zone where concrete is being poured in the stage.
"H" indicates the zone where concrete has hardened in the previous stage.
For "Zone", see Figure 3.8-93(25).

Example: Case 1, Stage 3
3.1m thick concrete is being placed into Zone 3. Concrete pour for Zones 1 and 2 has been completed in Stages 1 and 2, and concrete in the zones is considered to be hardened. Therefore, Zone 3 is marked as "P", and Zones 1 and 2 are marked as "H".

Table 3.8-93(5) Maximum Principal Tensile Stress in 0.9 m Thick Slab

Case	Soil Condition (MPa)		
	Soft Soil	Hard Spot	Soft Spot
1	1.96	1.76	1.33
2	1.99	1.50	1.83
3	2.12	1.69	1.39

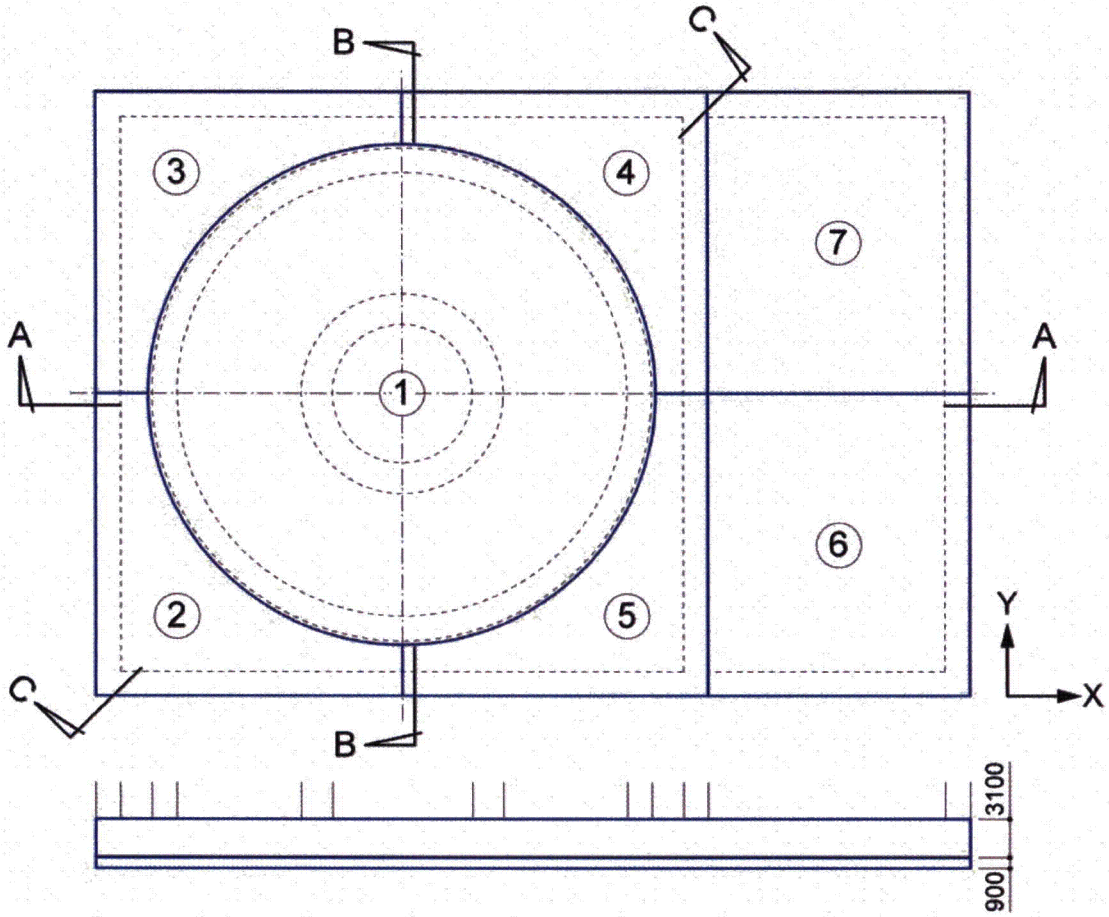
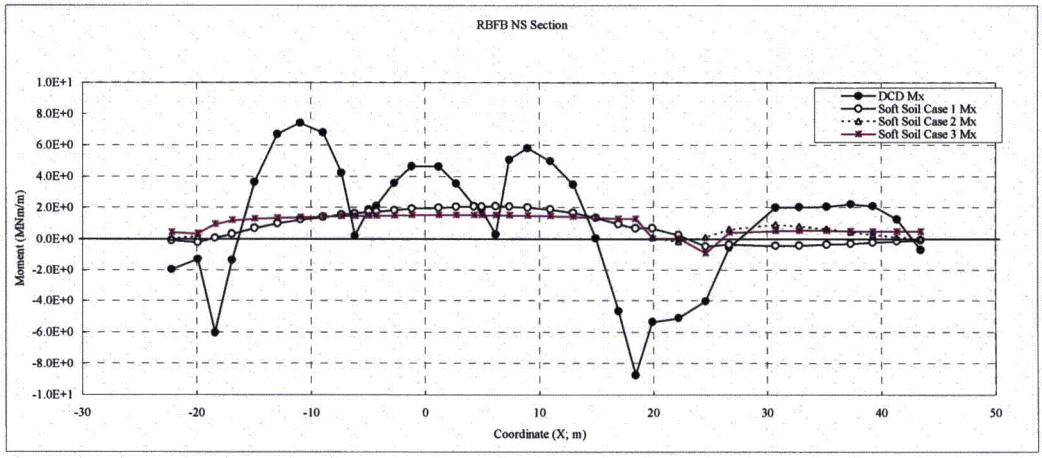
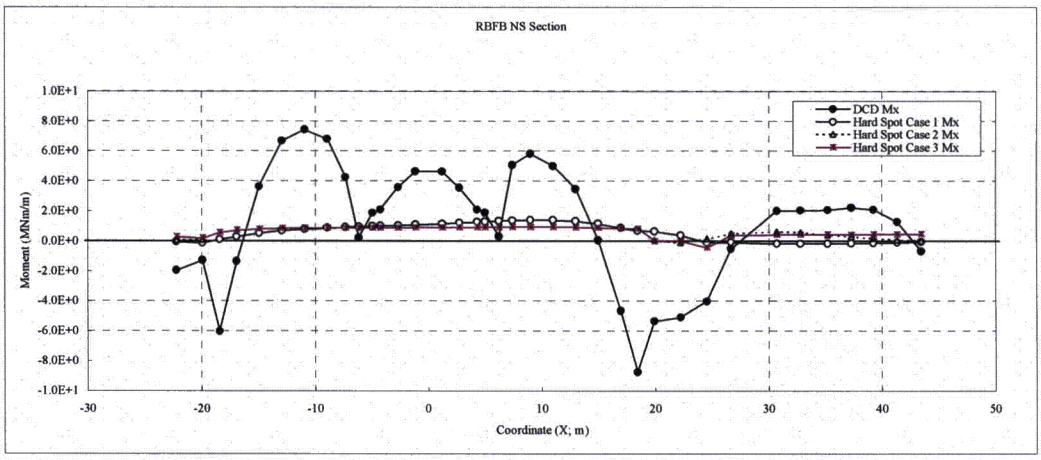


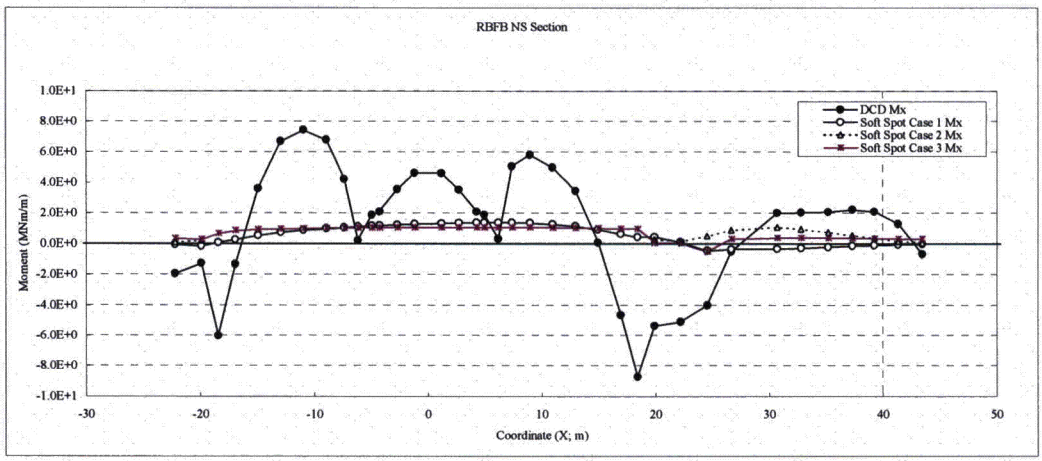
Figure 3.8-93(25) Zone of Basemat for Concrete Pour



(a) Soft Soil

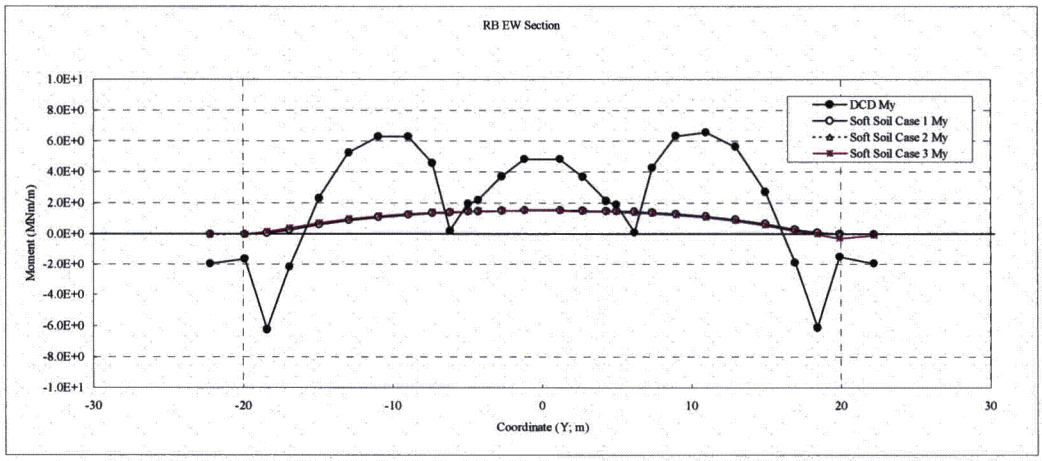


(b) Hard Spot

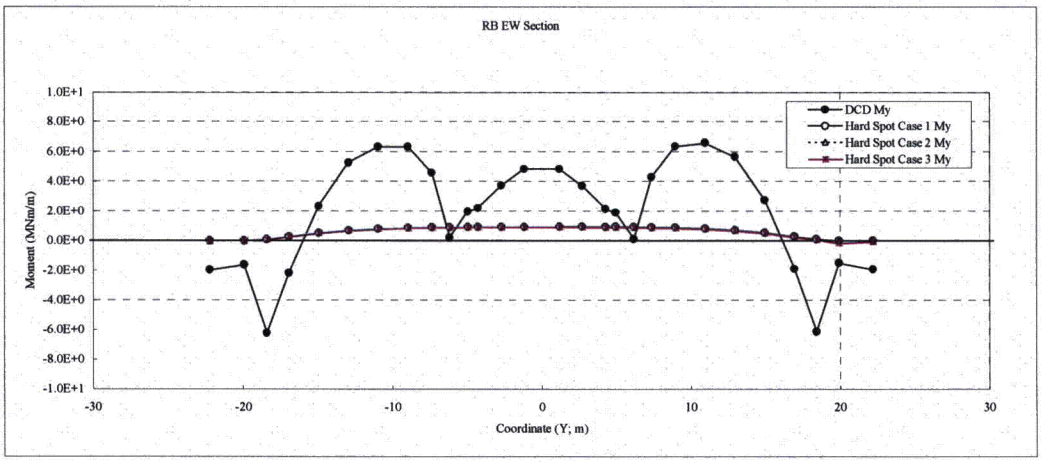


(c) Soft Spot

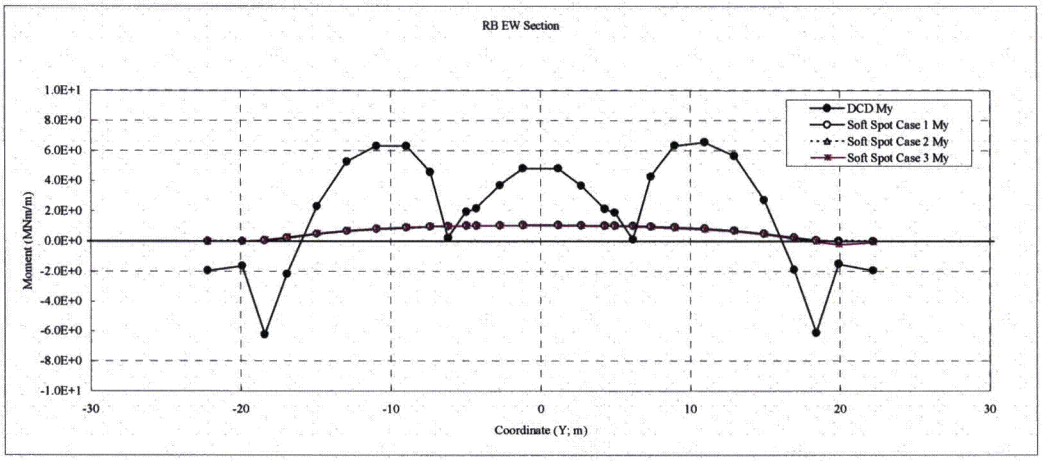
Figure 3.8-93(26) Comparison of Basemat Moment (Section A: Moment in X-dir., Mx)



(a) Soft Soil

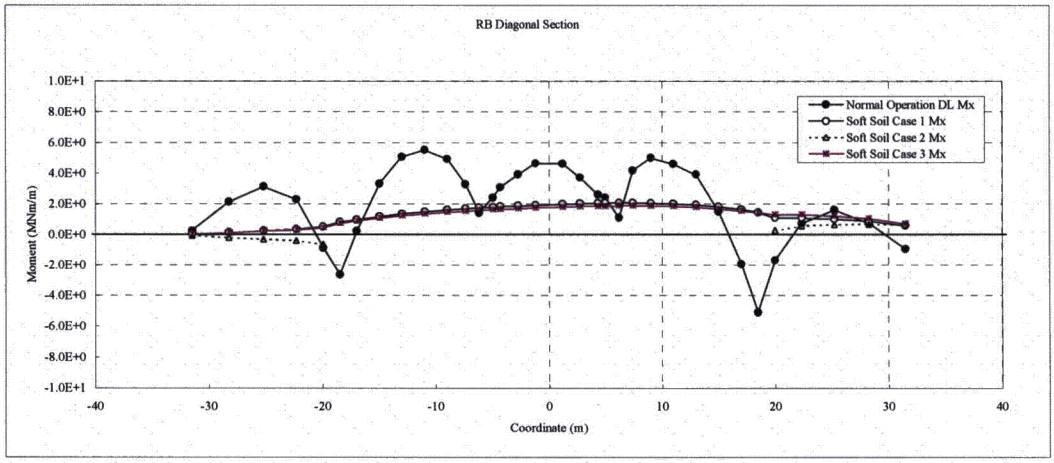


(b) Hard Spot

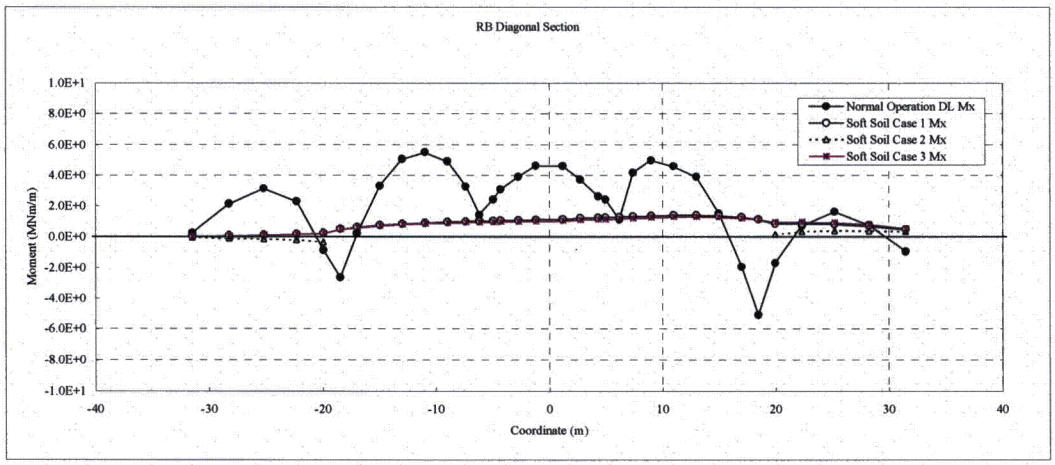


(c) Soft Spot

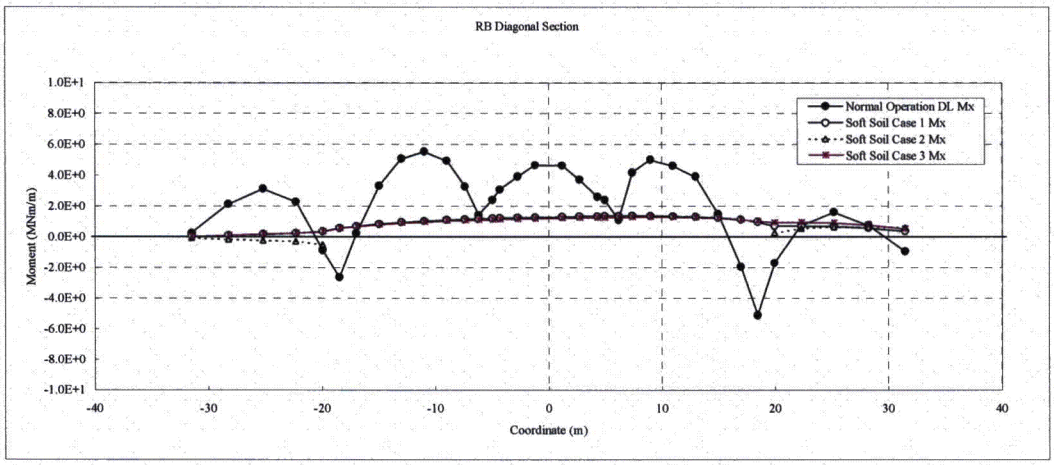
Figure 3.8-93(27) Comparison of Basemat Moment (Section B: Moment in Y-dir., My)



(a) Soft Soil

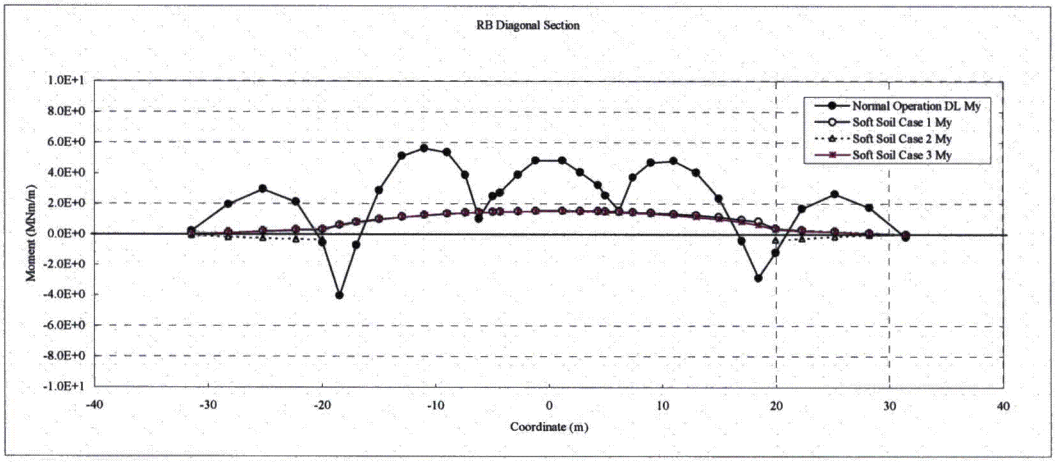


(b) Hard Spot

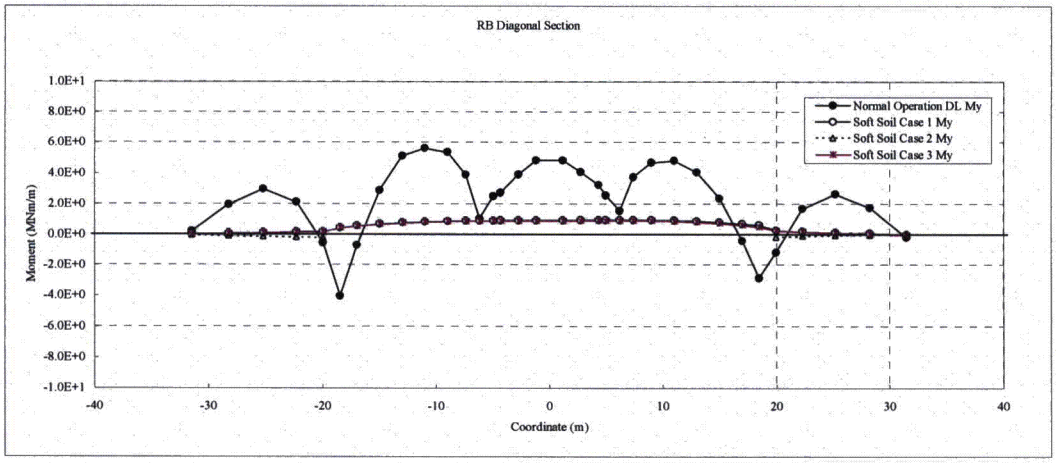


(c) Soft Spot

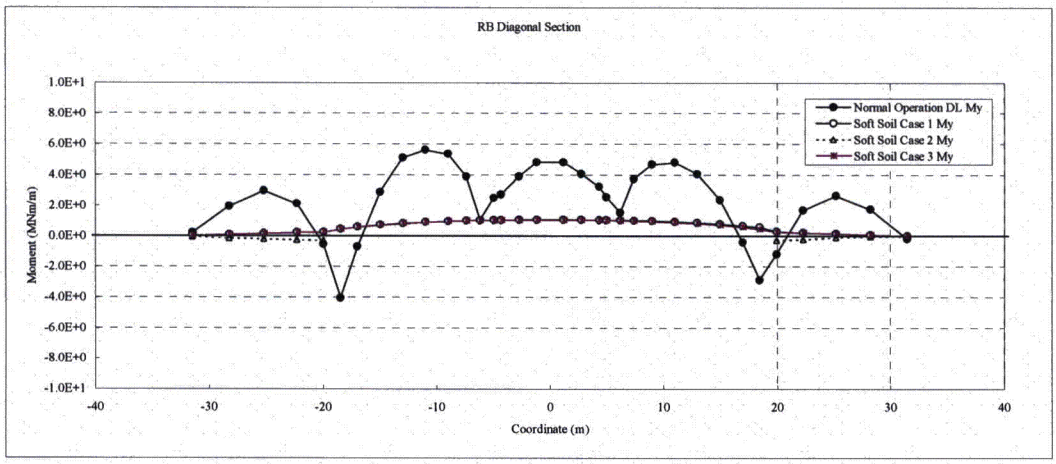
Figure 3.8-93(28) Comparison of Basemat Moment (Section C: Moment in X-dir., Mx)



(a) Soft Soil

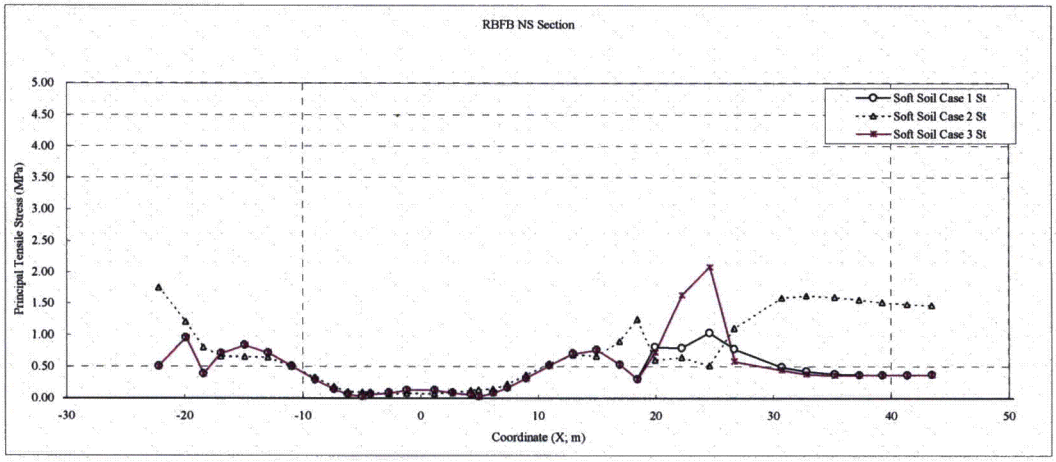


(b) Hard Spot

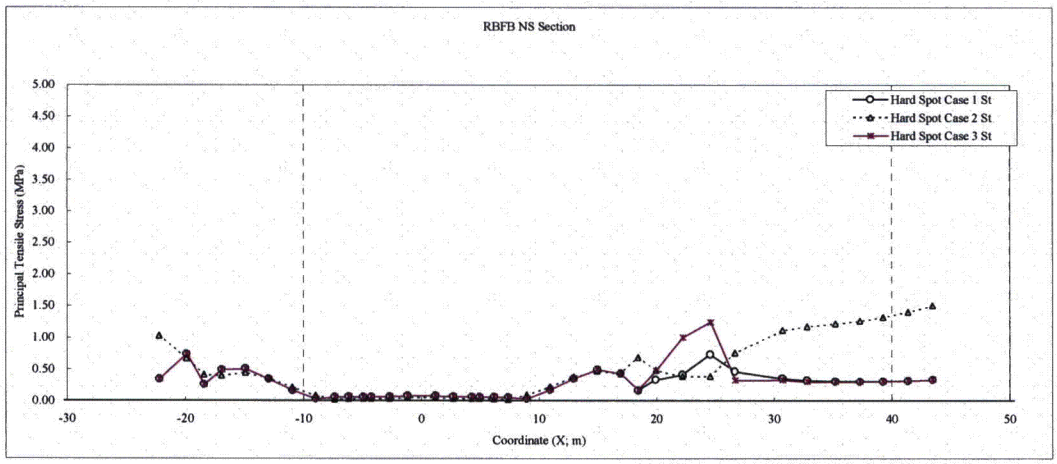


(c) Soft Spot

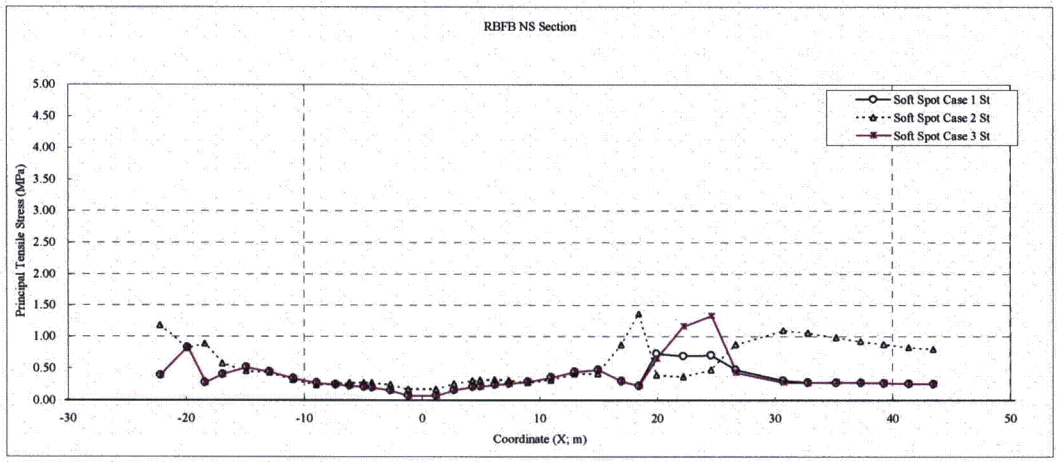
Figure 3.8-93(29) Comparison of Basemat Moment (Section C: Moment in Y-dir., My)



(a) Soft Soil

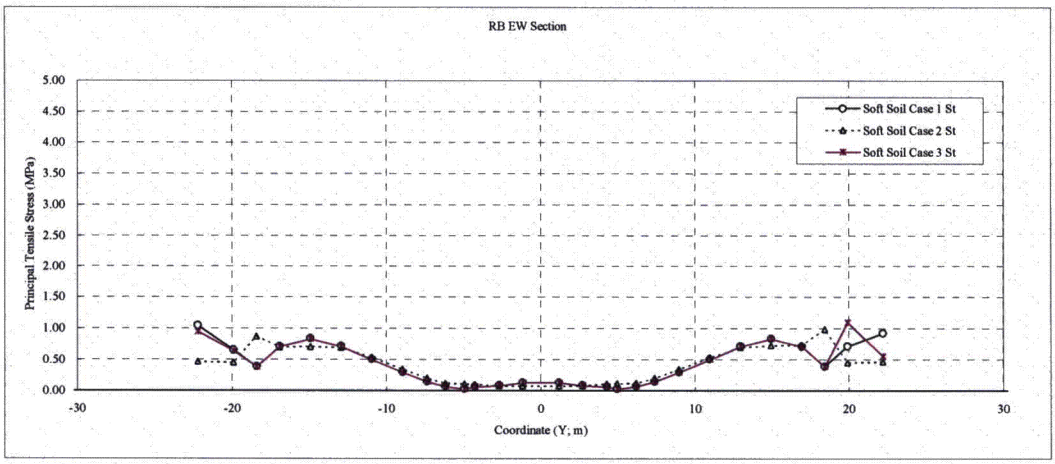


(b) Hard Spot

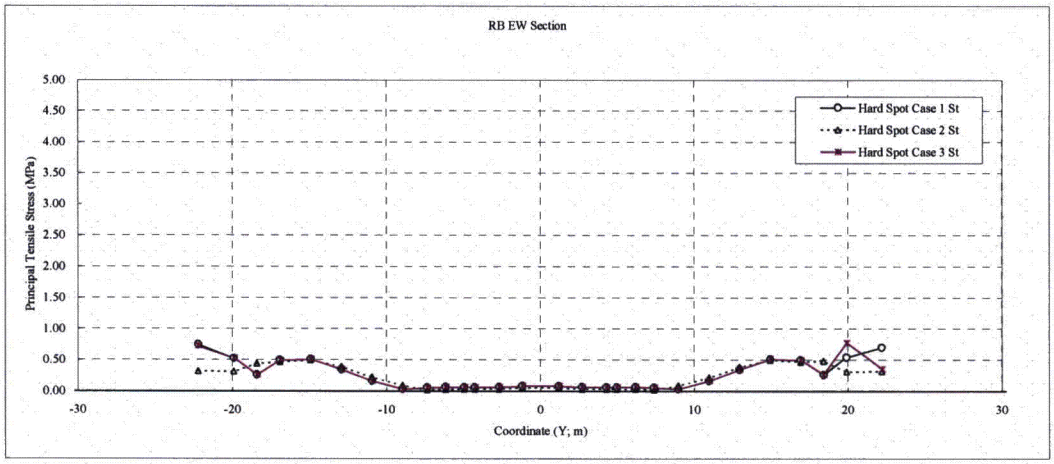


(c) Soft Spot

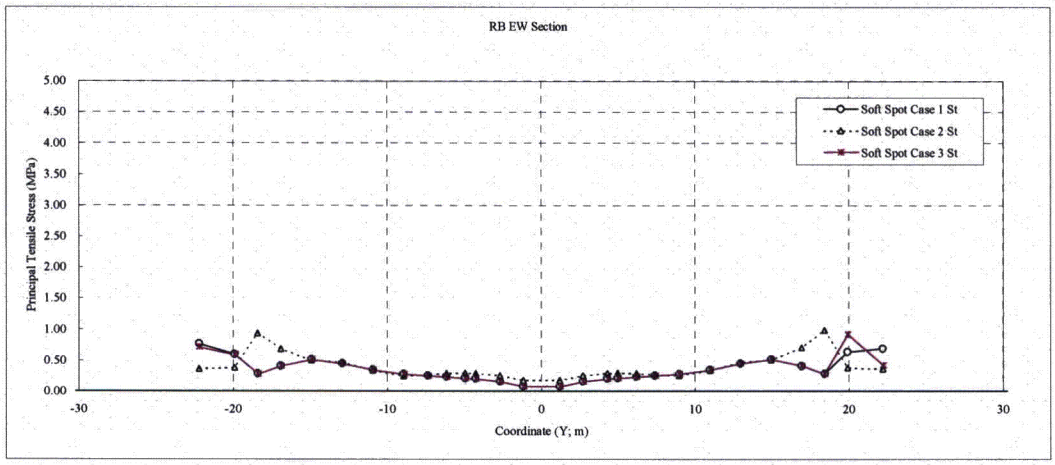
Figure 3.8-93(30) Comparison of Principal Tensile Stress in 0.9 m Thick Slab (Section A)



(a) Soft Soil

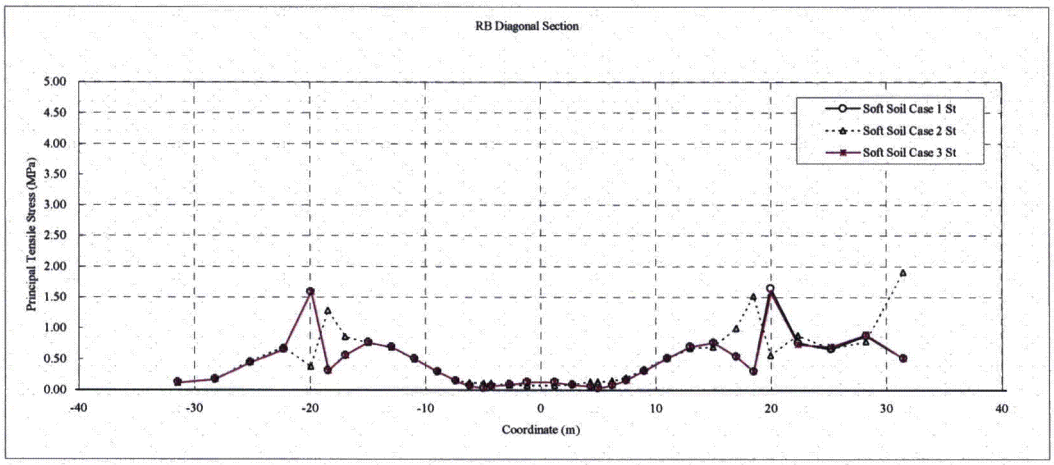


(b) Hard Spot

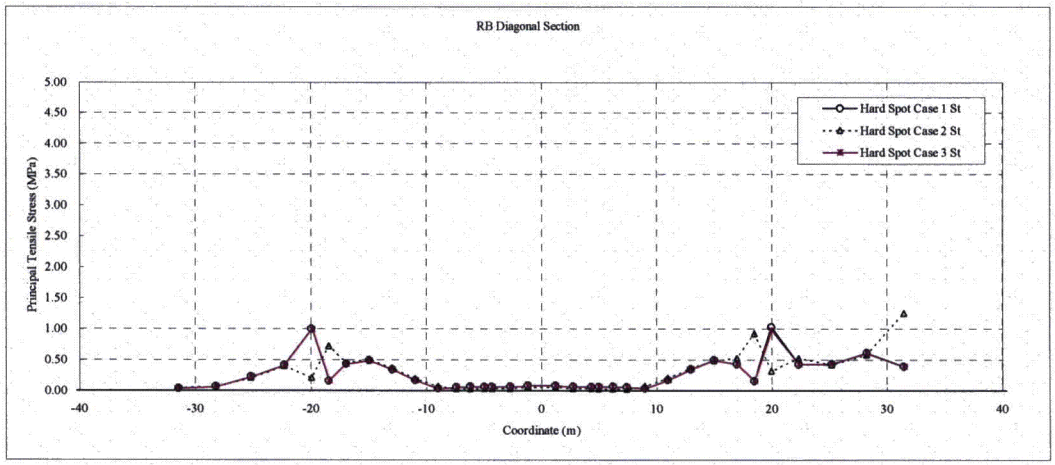


(c) Soft Spot

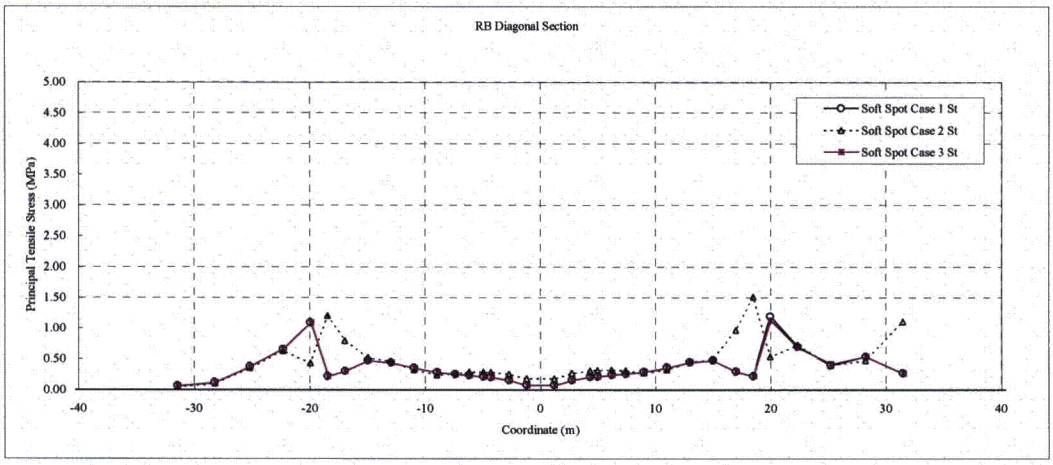
Figure 3.8-93(31) Comparison of Principal Tensile Stress in 0.9 m Thick Slab (Section B)



(a) Soft Soil



(b) Hard Spot



(c) Soft Spot

Figure 3.8-93(32) Comparison of Principal Tensile Stress in 0.9 m Thick Slab (Section C)

Evaluation for NRC RAI 3.8-93 (6)

Basemat Design for Construction Phase Considering Horizontal Variation of Soil Springs

1. Scope

The evaluation provided in the original response to NRC RAI 3.8-93 in MFN 06-407 is expanded herein to confirm the basemat design adequacy during the construction phase, taking into account both "Hard Spot" and "Soft Spot" horizontal variation of soil springs.

2. Analysis Conditions

The analysis condition is the same as in the original response to NRC RAI 3.8-93 plus the varying soil conditions under the basemat. After the completion of the basemat, several parts of the building will be constructed based on a planned construction sequence. This analytical study assesses the stress on the basemat during this construction period.

2-1. Construction Sequence

Per the original response to NRC RAI 3.8-93, the RBFB is assumed to be built sequentially outward as shown in Figure 3.8-93 (4). The assumed sequence is as follows:

Step 1. Pedestal poured up to 5m (below the floor EL-6400, approximately)

Step 2. Apply loads from pour of the RCCV and B3F structure

Step 3. Add pour of exterior walls in RB

Step 4. Add pour of walls in FB area

2-2. Soil Conditions

The following two conditions are considered:

- Hard Spot: Hard (stiffness is three times that of Soft soil; Softx3) below the RPV Pedestal region and Soft condition at the edge of basemat
- Soft Spot: Soft condition below the RPV Pedestal region and Hard (stiffness is three times that of Soft soil; Softx3) at the edge of basemat

2-3. Analysis Method

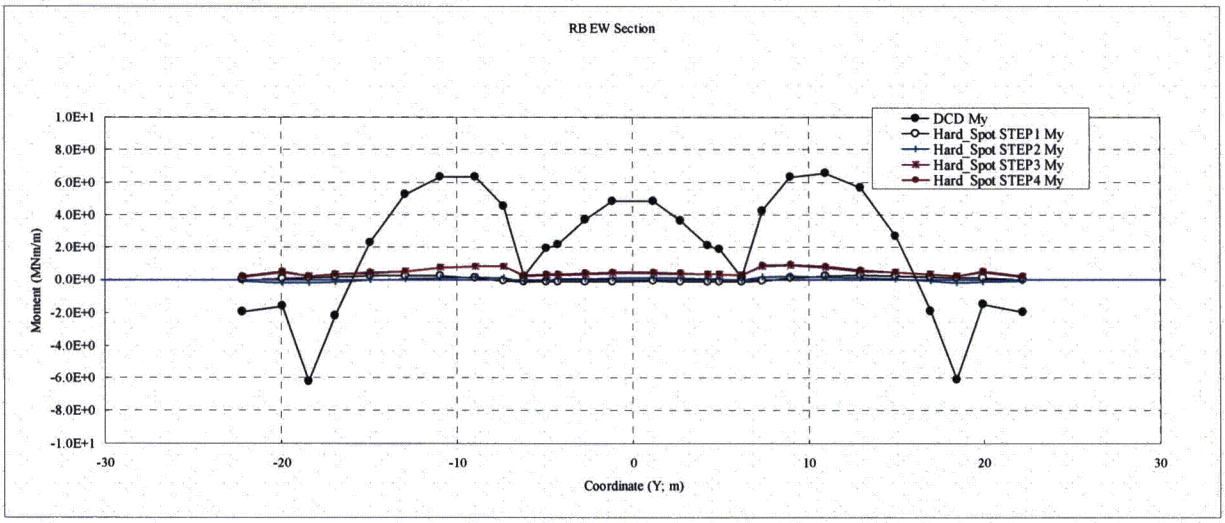
The analytical model has been extracted from the global FEM model used for the DCD design. The dead loads are generated within the program considering element thickness and density of concrete. The analytical conditions are as follows:

- FEM Model: Based on the "Modified Truncated Model (a part of Global FEM Model).

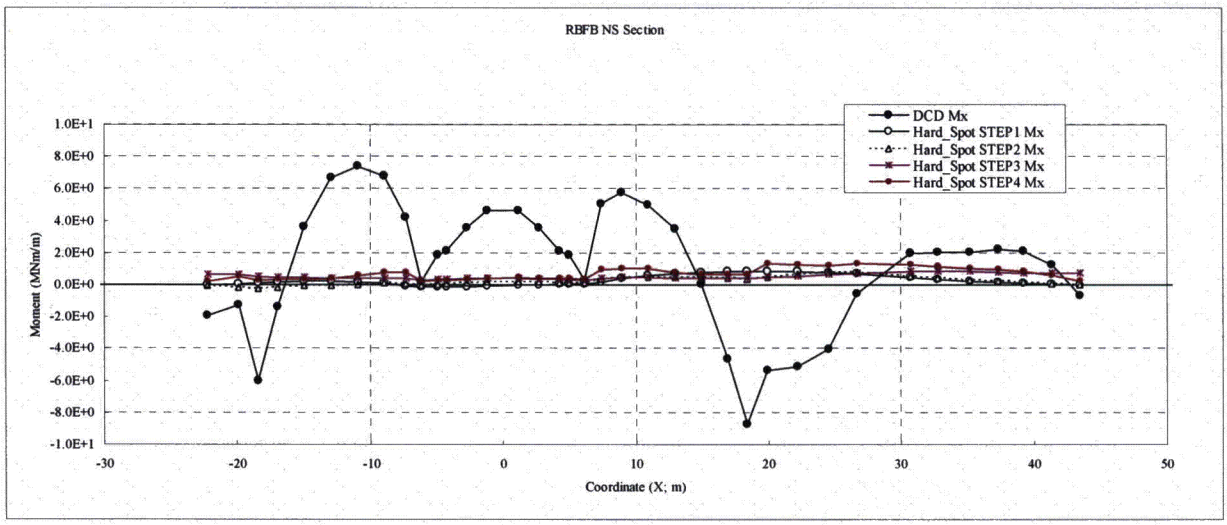
- Soil Condition: "Hard Spot" and "Soft Spot" are shown in Figure 3.8-93 (14). Using the Softx3 is considered as stiffer soil springs under the basemat.
- Load: Dead Load

3. Analysis Results

Figures 3.8-93 (33) and (34) show bending moments of the basemat compared to those of the DCD design (normal operation). The results indicate that the bending moment of the DCD design envelope is larger than the bending moment during the construction phase.



(a) E-W Section



(b) N-S Section

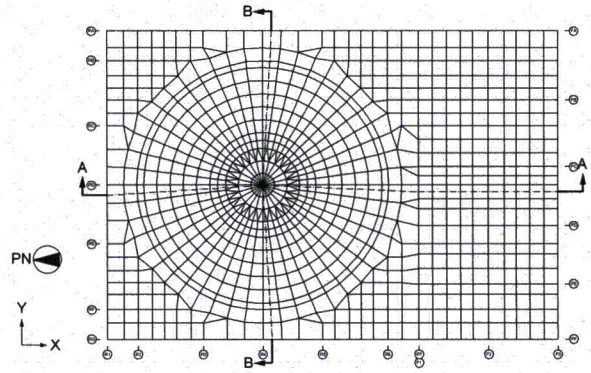
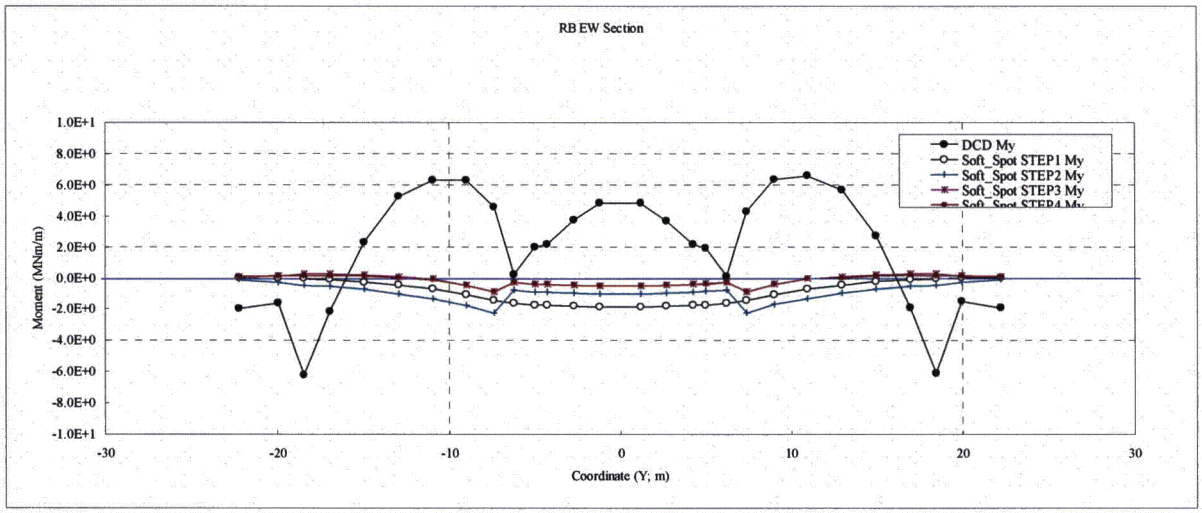
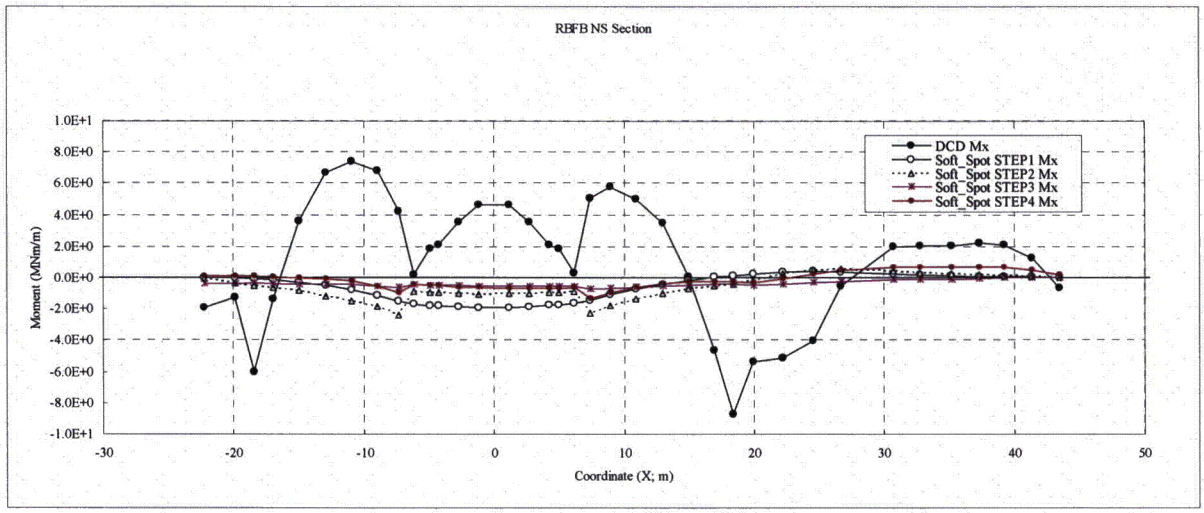


Figure 3.8-93(33) Comparison of Basemat Sectional Moments (Hard Spot)



(a) E-W Section



(b) N-S Section

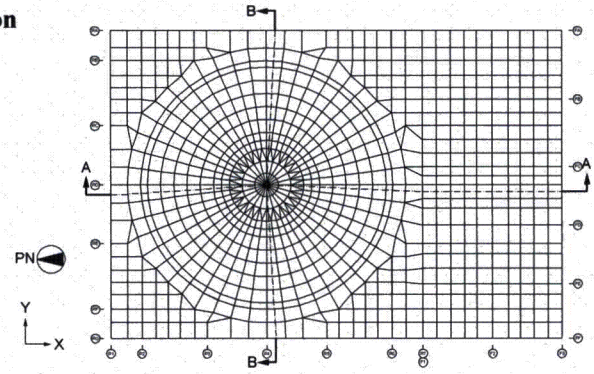


Figure 3.8-93(34) Comparison of Basemat Sectional Moments (Soft Spot)

DCD Tier 2 Table 2.0-1 and Subsection 3G.1.5.5 have been revised. DCD Tier 2 Subsections 3G.1.5.5.2, 3G.1.5.5.3, 3G.1.5.5.4 & 3G.2.5.5.1 have been added. The pages (pp. 2.0-4, 2.0-6, 3G-16, 3G-17 & 3G-194) revised in DCD Tier 2 Revision 3 for this response are attached.

DCD Impact

As stated above.

NRC RAI 3.8-93, Supplement 2

NRC Assessment from Chandu Patel E-mail Dated May 24, 2007

The staff requests the applicant to address the following:

(1) It is noted that the settlement values in DCD Tier 2 Table 2.0-1 are the same as those specified in DCD Tier 1 Table 5.1-1. The DCD should clearly state that the COL applicant must estimate the settlement by an analysis using actual site conditions and show that they are acceptable when compared to the values specified in DCD Tier 1 Table 5.1-1.

(2) DCD Tier 1 Table 5.1-1 and DCD Tier 2 Table 2.0-1 now requires that the ratio of the largest to the smallest shear wave velocity over the mat foundation width at the foundation level should not exceed 1.7. Clarify that this requirement is imposed to ensure that the bending moments on the basemat do not exceed the design allowable for horizontal soil spring variations that may vary by a factor of 3 from the basemat center to the basemat edge. Also describe how such a variation in shear wave velocity over the mat foundation was considered in the seismic analysis of the RB/FB and Control buildings. If this variation was not considered in the seismic soil structure interaction (SSI) analysis provide the appropriate criteria for the permissible variation in shear wave velocity to be used by the COL applicant, along with the technical bases for the criteria. The criteria in DCD Tier 1 Table 5.1-1 and DCD Tier 2 Table 2.0-1 should be revised accordingly.

(3) In response to this RAI, the applicant has studied several construction sequences and concluded that they have no effect on the basemat design. However, it is difficult to conclude that the worst loading condition has been considered. The criteria in DCD Tier 1 Table 5.1-1 and DCD Tier 2 Table 2.0-1 should require the COL applicant to review the construction sequences considered by GE in the design of the RB/FB and CB buildings. If the COL applicant proposes to use a construction sequence that is substantially different than that studied by GE, the COL applicant should be required to demonstrate that their proposed sequence does not cause a problem.

(4) Figure 3.8-93 (12)-d compares basemat moments resulting from differential settlement that are higher than the moments used for the DCD design condition. Explain why these higher moments are acceptable.

(5) As stated by the applicant in the response, Figure 3.8-93(16)-c indicates that the Softx3 case exceeds the base case (DCD) under the "Hard Spot" condition. The applicant states that for the design allowable, slightly less than 3x soft or hard conditions is used. However, Figure 3.8-93(16)-d indicates that the Softx2 case exceeds the base case (DCD) under the "Hard Spot" condition with results that appear to be identical to those in Figure 3.8-93(16)-c. Clarify what is meant by "slightly less than 3x soft or hard conditions is used." Also compare the moments shown in these two figures with the basemat moment design capacities in both directions across the entire basemat and provide the technical justification for predicted moments that are higher than the design allowable.

GEH Response

(1) In DCD Tier 2 Subsection 2.0-1-A, the COL applicant referencing the ESBWR DCD is required to demonstrate that the site characteristics, which include settlement values, of a given site fall within ESBWR DCD design parameter values shown in DCD Tier 2 Table 2.0-1. Site-specific settlement values are compared to the settlement values specified in DCD Tier 2 Table 2.0-1 to show that they are bounded. This is performed for the COL application. Settlement values have been deleted from DCD Tier 1 Table 5.1-1 in Revision 4. This is consistent with ABWR and AP1000 DCD Tier 1 in which settlement is not an ITAAC item.

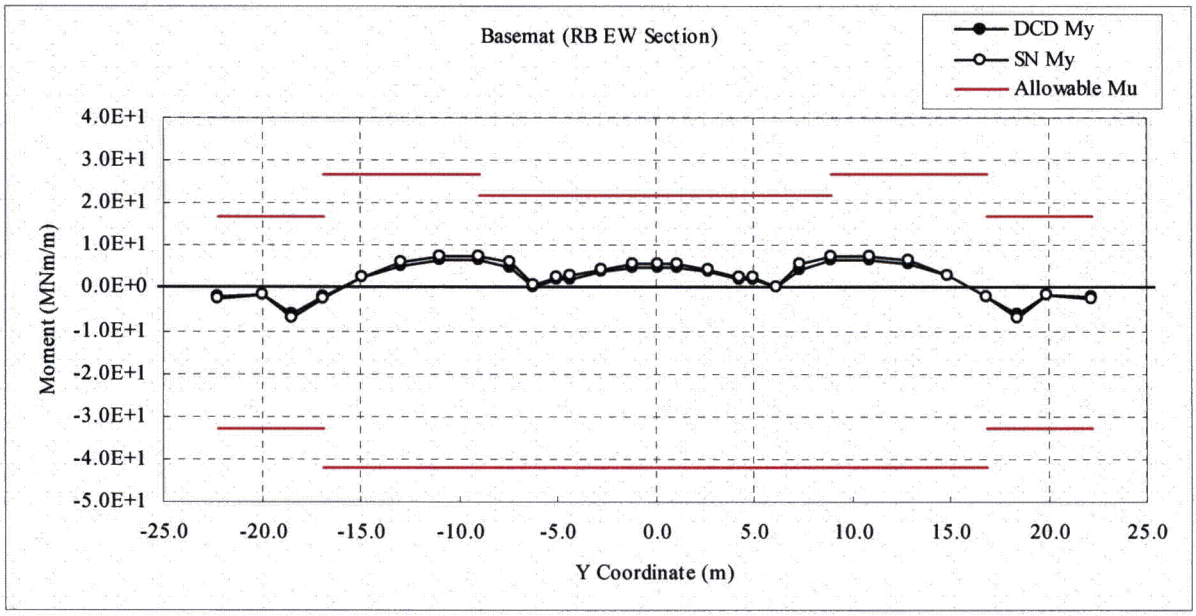
(2) The intent of the 1.7 factor for shear wave variation is to ensure that the bending moments on the basemat do not exceed the design allowable for horizontal soil spring variations that may vary by a factor of 3 from the basemat center to the basemat edge.

Horizontal variation of shear wave velocity is not considered in the seismic SSI analysis. Such variation is not a common practice and is not required since the purpose of the SSI analysis is to predict global structural response. In the SSI analysis the effect of soil uncertainties is typically taken into account in the form of 3 soil profiles, best estimate, lower bound and upper bound. A wide range of shear wave velocity variations is considered in the ESBWR Standard Plant design SSI analysis for generic sites. Therefore, no additional criteria for permissible horizontal variation of shear wave velocity for SSI analysis are required for COL to meet. The existing criteria stating "The ratio of the largest to the smallest shear wave velocity over the mat foundation width at the foundation level does not exceed 1.7" in DCD Tier 2 Table 2.0-1 are sufficient.

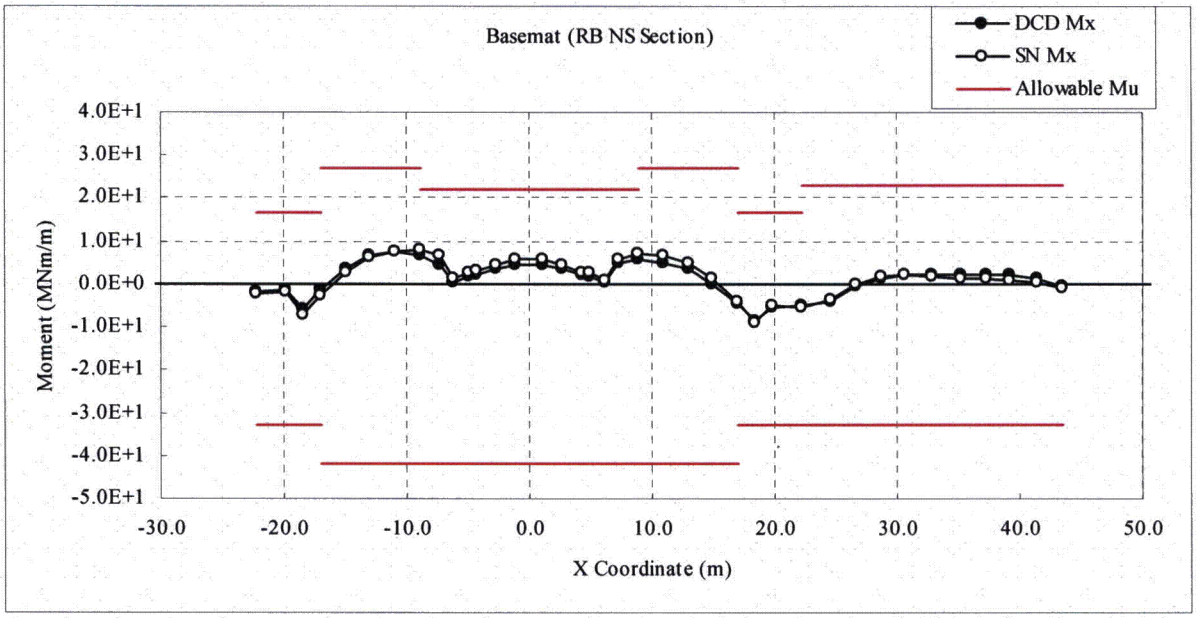
(3) The following sentence will be added to DCD Tier 2 Subsection 3G.1.5.5.3: "The actual construction sequence, if substantially different from the sequences considered in the design, is ensured not to adversely impact the basemat design".

(4) The higher moments resulting from differential settlement are acceptable since they are well within the allowable moment capacities, calculated using beam theory, at various sections of the basemat. Figure 3.8-93(35) is an update to Figure 3.8-93(12)-d that shows the allowable moment capacities.

(5) The statement "slightly less than 3x soft or hard conditions is used" is intended to mean that the soft×3 case is selected as a limiting horizontal variation of soil springs since the soft×3 and soft×2 results presented in Figures 3.8-93(16)-c and 3.8-93(16)-d are essentially the same. Figures 3.8-93(36) and 3.8-93(37) are updates to Figures 3.8-93(16)-c and 3.8-93(16)-d, respectively, that show the allowable moment capacities, calculated using beam theory, at various sections of the basemat. As shown, the predicted basemat moments for the soft×3 and soft×2 cases are well within the design capabilities.

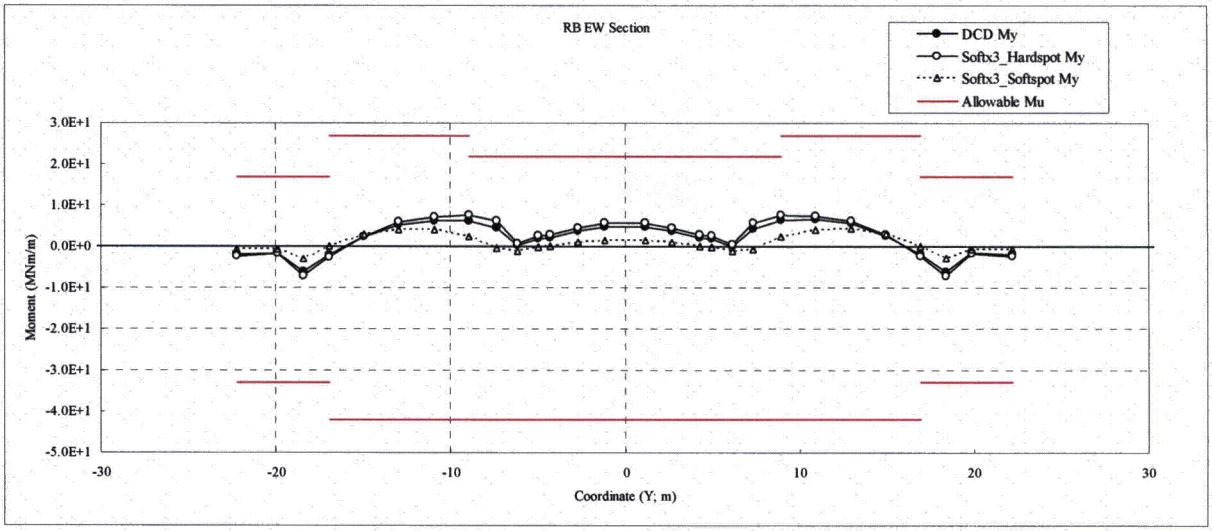


(a) My in E-W Section

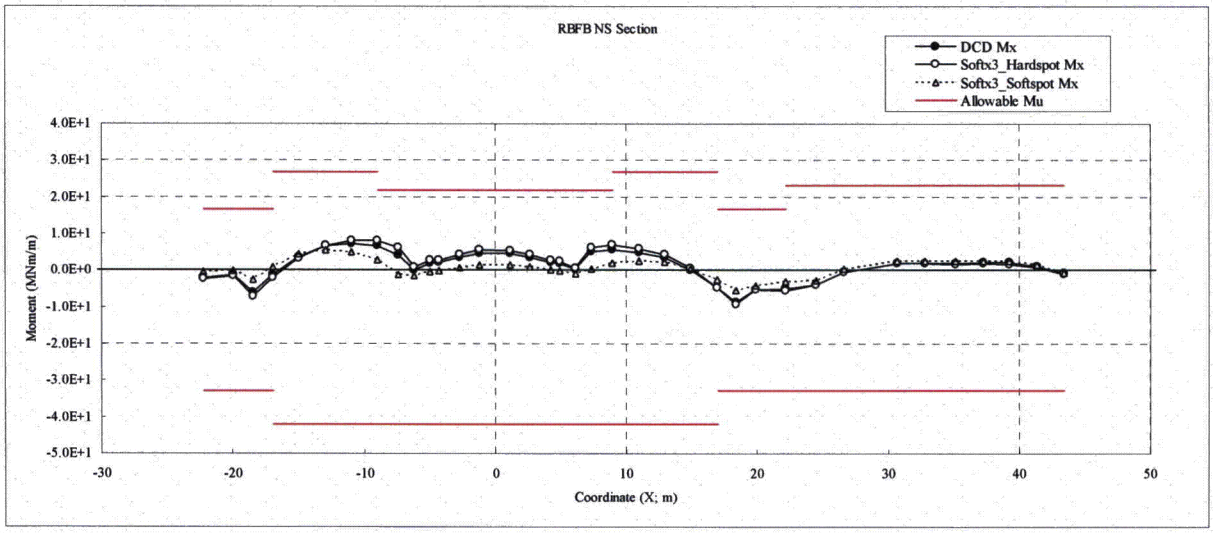


(b) Mx in N-S Section

Figure 3.8-93(35) Comparison of Basemat Sectional Moments (RBFB, S-N direction)

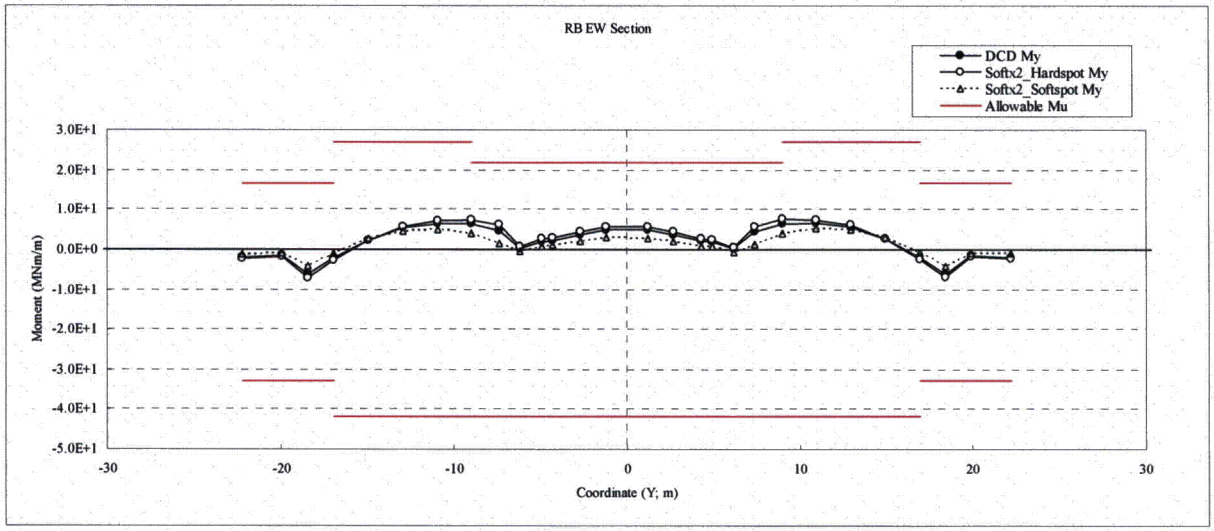


(a) My in E-W Section

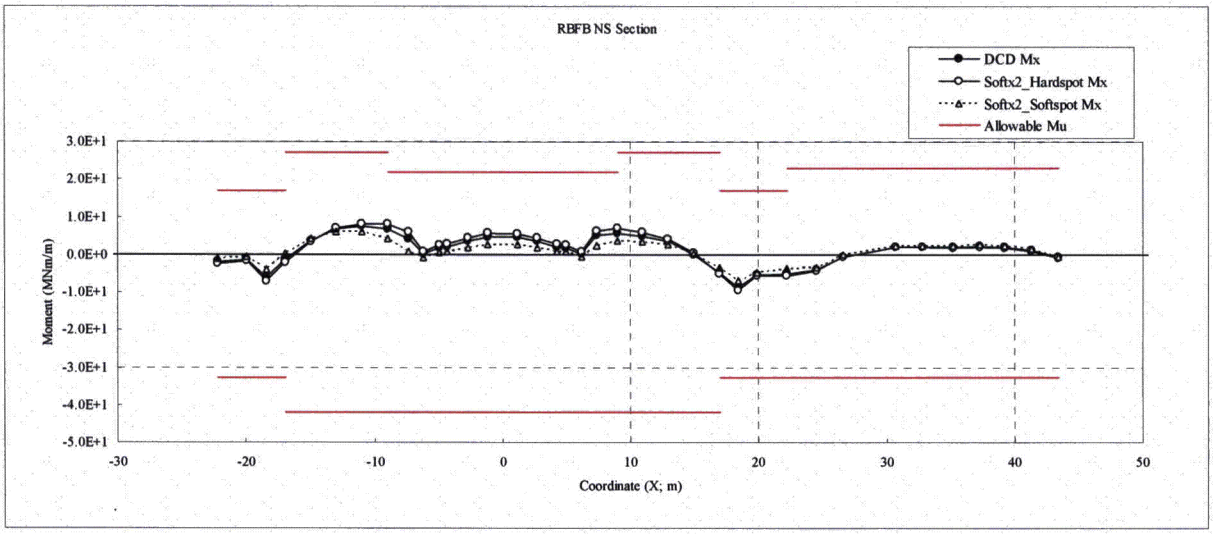


(b) Mx in N-S Section

Figure 3.8-93(36) Comparison of Basemat Sectional Moments (soft x3)



(a) My in E-W Section



(b) Mx in N-S Section

Figure 3.8-93(37) Comparison of Basemat Sectional Moments (soft x2)

DCD Impact

A markup of DCD Tier 2 Subsection 3G.1.5.5.3 was provided in MFN 06-407, Supplement 3.

NRC RAI 3.8-93, Supplement 3

The RAI Supplement 2 response, transmitted in GEH letter dated November 28, 2007, provided information to address five items related to the foundation and soil settlement, seismic soil shear wave velocity requirement, construction sequences, and soil stiffness studies. To address Item (5) in the supplemental response, the staff requests GEH to clarify whether the COL applicant or someone else will determine if the construction sequence is substantially different from the sequences considered in the design, and if substantially different, who will ensure that they will not adversely impact the basemat design. The commitment regarding the construction sequence, with this additional clarification, should also be included in DCD Tier 2 Subsection 2.

GE Response

The construction sequence studies performed and discussed in previous supplemental responses to this RAI and documented in DCD Tier 2 Subsection 3G.1.5.5.3 have taken into account all possible variations in common construction practice and demonstrate that the construction sequence has negligible impact on basemat stresses.

The last paragraph of DCD Tier 2 Subsection 3G.1.5.5.3 will be revised to read: "The actual construction sequence will be consistent with the sequences evaluated above and will be reflected in the construction specification."

DCD Impact

DCD Tier 2 Subsection 3G.1.5.5.3 will be revised in the next revision as noted in the attached markup.

3G.1.5.5.3 Effect of Construction Sequence

The basemat design is checked against the loads expected during construction of the basemat. The RB/FB basemat is divided into 7 zones for concrete pour and these zones are investigated for three possible construction sequences. The moment differences between sequences considered are negligibly small in comparison with the moments used in the basemat design. In addition to basemat construction sequence, the impact of the building structures construction sequence, i.e., RPV Pedestal, RCCV and walls, on the basemat design is also investigated. The evaluation results confirm that the building structures construction sequence has negligible effect on the basemat design. These studies include horizontal soil spring variations, "Hard Spot" and "Soft Spot" as described in Subsection 3G.1.5.5.2.

The actual construction sequence~~, if substantially different from the sequences considered in the design, is ensured not to adversely impact the basemat design~~will be consistent with the sequences evaluated above and will be reflected in the construction specification.