BSC

Design Calculation or Analysis Cover Sheet

Complete only applicable items.

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2. Page 1

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Aging Facility (AP) Foundation Design

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See Section 5	95

RECORD OF REVISIONS

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DISCLAIMER

The calculations contained in this document were developed by Bechtel SAIC Company, LLC (BSC), and are intended solely for the use of BSC in its work for the Yucca Mountain Project.

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ACRONYMS / ABBREVIATIONS

Acronyms

CD	compact disc
DPC	dual-purpose canister
HAM	horizontal aging module

Abbreviations

AP	Aging Facility
SADA	Seismic Analysis and Design Approach
ft	feet
k	kips
kcf	kips per cubic foot
ksf	kips per square foot
pcf	pounds per cubic foot

1. PURPOSE

The purpose of this calculation is to perform a preliminary foundation design for aging pad 17P, shown in 170-P10-AP00-00102-000, *Aging Facility General Arrangement Aging Pad 17P Plan* (Reference 2.2.2), and for aging pad 17R, shown in 170-P10-AP00-00103-000, *Aging Facility General Arrangement Aging Pad 17R Plan* (Reference 2.2.3), of the Aging Facility (AP), as shown in 170-P10-AP00-00101-000, *Aging Facility General Arrangement Aging Pad Area Plan* (Reference 2.2.1).

Aging pads 17P and 17R are designed as a holding area for aging overpacks. The foundation design for horizontal aging modules (HAMs) sitting at south end of aging pad 17R is addressed in Section 6.7.

The shear and flexural reinforcements for the foundation are determined in this calculation in accordance with ACI 349-01, *Code Requirements for Nuclear Safety Related Concrete Structures (ACI 349-01) and Commentary (ACI 349R-01)* (Reference 2.2.8). The design is based on the maximum potential weight and geometry of the site transporter, *Yucca Mountain – Site Transporter MEE.* V0-CY05-QHC4-00459-00032-001 (Reference 2.2.14), *Site Transporter Propel System.* V0-CY05-QHC4-00459-00042-001 (Reference 2.2.20), the aging overpacks as shown in 170-MJ0-HAC0-00101-000, *Aging Overpack Outline / Interface* (Reference 2.2.17), and in 170-MJ0-HAC0-00201-000, *Aging Facility Vertical DPC Aging Overpack Mechanical Equipment Envelope Sheet 1 of 2* (Reference 2.2.18). Throughout this document, the aging overpacks are referred to as casks.

The basis of design for the AP is defined in 000-3DR-MGR0-00300-000, *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.5, Section 10).

2. REFERENCES

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2.2.6 DOE (U.S. Department of Energy) 2007. *Software Validation Report for: SAP2000 Version 9.1.4.* Document ID: 11198-SVR-9.1.4-01-WinXP. Las Vegas, Nevada: U.S. Department of Energy, Office of Repository Development. ACC: MOL.20070118.0264. [DIRS 179105]

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2.2.15 BSC 2005. *Design of a Concrete Slab for Storage of SNF and HLW Casks.* 170-00C-HAP0-00100-000-00B. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20050214.0007; ENG.20050829.0014.

2.2.16 BSC 2007. *Supplemental Soils Report.* 100-S0C-CY00-00100-000-00C. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070222.0001.

2.2.17 BSC 2007. *Aging Overpack Outline / Interface.* Engineering drawing. 170-MJ0-HAC0-00101-000 REV 002. Las Vegas, Nevada: Bechtel SAIC Company. ACC: ENG.20070606.0009.

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2.3 DESIGN CONSTRAINTS

None

2.4 DESIGN OUTPUTS

Results of this calculation will be used in developing the AP foundation concrete drawings.

3. ASSUMPTIONS

3.1 ASSUMPTIONS REQUIRING VERIFICATION

The following assumptions require verification. These assumptions are being tracked in the CalcTrac Database.

3.1.1 Transporter Wheel Contact Area

It is assumed that each track load is uniformly distributed on six elements, each with dimensions of 3 ft by 3 ft at 15 ft spacing, to approximate the actual load of a loaded transporter on the aging pad.

Rationale–The rationale for this assumption is that detail dimensions, used in SAP2000 (Reference 2.2.11) modeling, approximate with transporter wheel contact areas on drawing (Reference 2.2.20).

Where used: Section 6.3.1-A and C.

3.1.2 Aging Pad to be founded on Alluvium

The aging pad is assumed to be founded on alluvium.

Rationale–The rationale for this assumption is from *Supplemental Soils Report* (Reference 2.2.16), which indicates alluvium to be under the nuclear facilities. The AP is further north, therefore, it is reasonable to assume alluvium as the foundation soil. This will be confirmed in final design.

Where used: Section 6.2.

3.1.3 Weight of HAM

The loaded weight of a HAM is assumed to be 646.5 kips.

Rationale–The drawing for HAMs (Reference 2.2.19) does not show weights. Weights are estimated in Section 6.3.1-D. The weight will be confirmed in final design.

Where used: Section 6.7.

3.1.4 Seismic Accelerations

Use 0.45g horizontal and 0.32g vertical acceleration for the concrete foundation mat and for the site transporter from 5E-4 annual probability of exceedance (APE) Damped Design Spectra (Reference 2.2.24).

Rationale–The concrete foundation and transporters are at grade level, therefore using 0.45g for horizontal and 0.32g for vertical forces as peak ground accelerations is appropriate.

Where used: Section 6.3.2.

3.1.5 Foundation Dimensions

Apron at east end from centerline cask is 20 ft, but 21 ft dimension is used in SAP2000 (Reference 2.2.11) model (References 2.2.2 and 2.2.3).

Rationale– 21 ft dimension for apron, coupled with 12 ft diameter for aging overpack and 18 ft center to center spacing makes 3 ft uniform spacing easier for modeling and it does not impact the results.

Where used: Section 6.1.

3.2 ASSUMPTIONS NOT REQUIRING VERIFICATION

3.2.1 Contour Plots for Reinforcing Design

Contour plots generated by SAP2000 (Reference 2.2.11) using maximum and minimum peak shell element values for shear and moment will be used in the design of the foundation mat.

Rationale–Using peak shell element values for shear and moment is appropriate for the concrete and reinforcement design, resulting in a conservative design.

Where used: Section 6.5.1.

4. METHODOLOGY

4.1 QUALITY ASSURANCE

This calculation was prepared in accordance with EG-PRO-3DP-G04B-00037 (Reference 2.1.1). The *Basis of Design for the TAD Canister-Based Repository Design Concept* (Reference 2.2.5, Section 10.1.2) classifies the AP as important to safety (ITS); therefore, the approved version of this calculation is designated as QA: QA.

4.2 USE OF SOFTWARE

The commercially available Microsoft Office Excel 2003 (11.8142.8132 SP2) spreadsheet code, which is part of the Microsoft Office 2003 Professional suite of programs, was used in this calculation. Microsoft Office 2003 Professional, as used in this calculation, is classified as Level 2 software usage as defined in IT-PRO-0011 (Ref. 2.1.2, Subsection 4.1). Microsoft Office 2003 is listed on the current *Controlled Software Report* and is identified with Software Tracking Number 610236-2003-00. It is also listed in the *Repository Project Management Automation Plan* (Ref. 2.1.3, Table 6-1). The Excel files are located in Attachment B of this document in the form of a compact disk (CD).Excel was operated on a PC system running the Windows XP Professional operating system.

MathCAD Version 13 was utilized to perform design calculations in Attachment D. MathCAD was operated on a PC system running the Windows XP Professional operating system. MathCAD as used in this calculation is considered as level 2 software usages as defined in IT-PRO-0011 (Ref. 2.1.2). MathCAD Version 13 is listed on the current Software Report (SW Tracking Number 611161-13-00), as well as the *Repository Project Management Automation Plan* (Ref. 2.1.3).

All MathCAD input values and equations are stated in the calculation. Checking of the MathCAD and Excel spreadsheet was done by using visual inspection and hand calculations to confirm the accuracy of the results.

SAP2000, Version 9.1.4 (Ref. 2.2.11), as used in this calculation, is classified as Level 1 software usage as defined in IT-PRO-0011 (Ref. 2.1.2, Subsection 4.1). This software is a commercially available computer program qualified to perform static and dynamic analysis of structural systems. This software is listed in the *Qualified and Controlled Software Report* and is identified with Software Tracking Number 11198-9.1.4-01. The software is operated on a PC system running the Windows XP Professional operating system. SAP2000 is used within the range of validation as documented in Ref. 2.2.6.

4.3 DESCRIPTION OF CALCULATION APPROACH

As stated in Section 1, the purpose of this calculation is to design AP foundation for the flexural and shear reinforcing requirements with demand/capacity ratio limited to 0.7.

Hand calculations were performed to calculate some of the loadings.

A finite element model of the AP foundation was developed using uniform spacing of 3 ft for grids in both directions. Two-joint link elements were used to model the stiffness of the underlying soil. Dead, live and seismic loads were applied to the model and loading combinations were developed that maximize the soil pressures on the structure

Having completed the linear static analysis by SAP2000 (Reference 2.2.11), it is also utilized to generate moment and shear contour plots, which will be used in designing the flexural and shear reinforcing in the foundation. In designing the flexural reinforcing a standard rebar pattern is selected and the corresponding moment capacity resulting from that reinforcing is computed. Per Assumption 3.2.1, maximum and minimum peak shell element values for shear and moment will be used in the design of the foundation mat. In evaluating the shear reinforcing requirements in the foundation the shear capacity of the concrete (without any shear reinforcing) is computed and if additional capacity required above the capacity provided by the concrete, the shear contour plots are utilized to determine shear reinforcing size and areas.

Details of the finite element analysis of the foundation are discussed in Section 6.

5. LIST OF ATTACHMENTS

		Number of Pages
Attachment A.	SAP2000 Input File	1 page + CD 1 of 1
Attachment B.	SAP2000 Output Files	1 page + CD 1 of 1
Attachment C.	Moment and Shear Contour Diagrams	85
Attachment D.	Aging Cask Stability Analysis (DBGM-2)	8

6. BODY OF CALCULATION

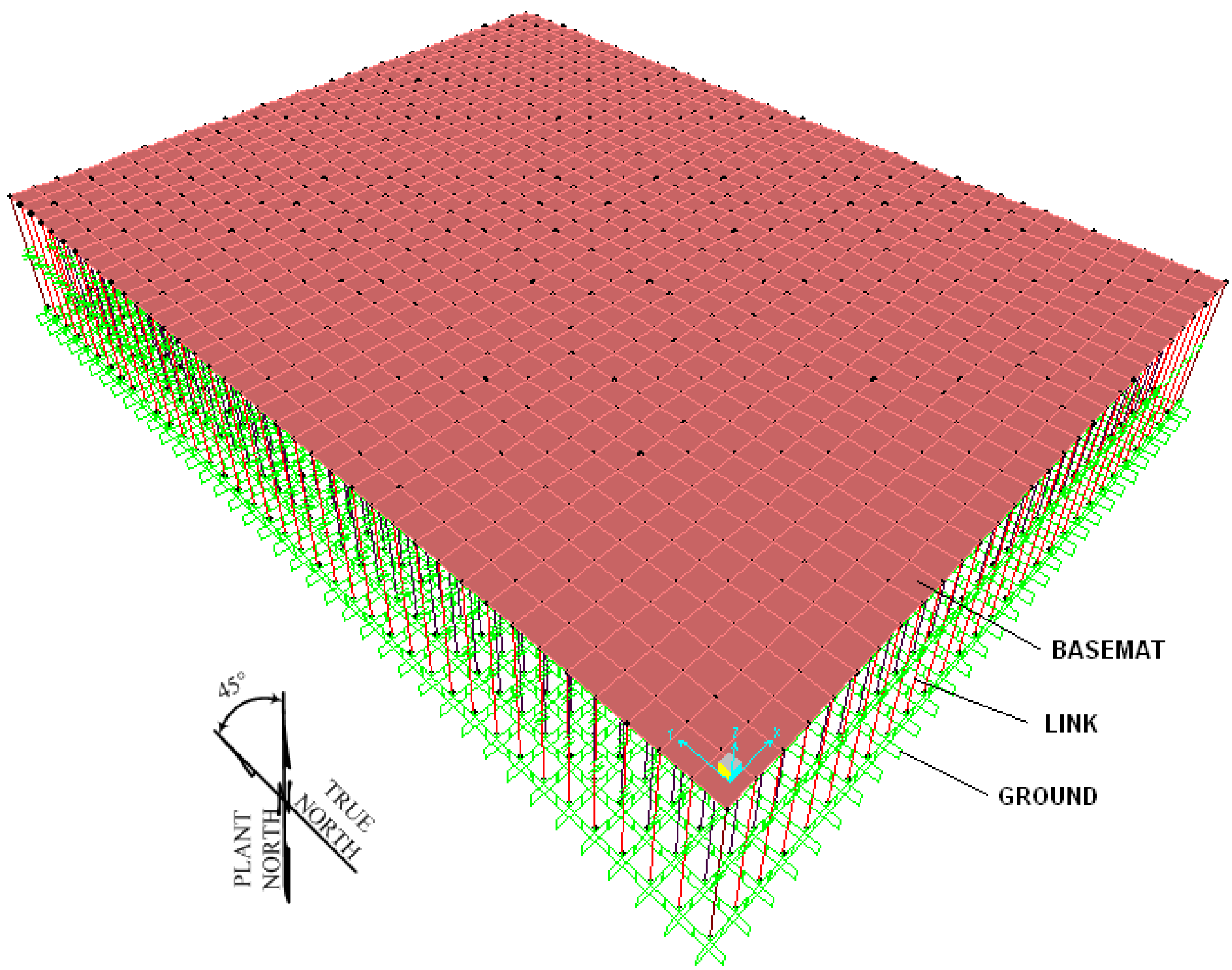
6.1 AGING PAD MODELING

The aging pad foundation mat is modeled from the general arrangement for AP (References 2.2.1 to 2.2.4) with small modification in dimension (Assumption 3.1.5) to facilitate a uniform 3 ft grid in both directions. The aging area for the vertical casks consists of a thick reinforced concrete mat covering area of varying length and constant 114 ft 0 in. width for aging overpacks. The mat design is based on a representative concrete mat of 87 ft 0 in. by 114 ft 0 in. and 3 ft 0 in. thick loaded with a set of sixteen casks with four rows of casks at 18 ft 0 in. spacing in both directions on each mat. The section of mat at the east end of aging pad is considered as representative of all remaining pad sections for design purposes. The considered mat has approximately 24 ft 0 in. aprons for access by the cask transporter vehicle on the north and south end and approximately 6 ft 0 in. and 15 ft 0 in. aprons at the west and east end respectively for pad considered in design.

A finite element model of the AP foundation was created using SAP2000 (Reference 2.2.11). The AP foundation is represented by shell elements with uniform size of 3 ft by 3 ft and area loads are selected to represent cask and transporter loading. The coordinate system, global origin, and orientation of the global axes are shown on Figure 6.1.1.

The shell elements used to model the foundation were located at a Z coordinate corresponding to the base of the foundation. In this case a 3 ft. thick slab is considered for the foundation mat thus the Z coordinate origin of the finite element mesh is located at Z = −3 ft.

To simulate the stiffness properties of the soil underlying the Foundation mat, a series of soil springs were utilized. The soil spring stiffness is computed using modulus of subgrade reaction (Reference 2.2.16, Table 2-2). This calculation uses these global springs to compute “local” springs to be placed under each joint in the Foundation mat mesh. The method used in determining the stiffness of these "local" springs is based on the contact area of the joint on the Foundation mat. There are 3 different size contact areas that make up the AP Foundation mat mesh. Table 6.1.1 displays the different contact areas, the number of these areas in the model, and the total area represented.



AP Foundation Model

Figure 6.1.1 Isometric View of the Model

Table 6.1.1 AP Foundation Mat SAP2000 Areas

Contact Area Label	Contact Area (ft^2)	# Of Joints	Total Area (ft^2)
Group A (100% Link)	9.00	1036	9324
Group B (50% Link)	4.5	130	585
Group C (25% Link)	2.25	4	9

In order to reasonably model the soil stiffness, the contact area is calculated for the AP Foundation Mat model. There are 3 different contact areas for all the 1170 joints of the Foundation Mat. The 3 different contact areas define the grouping of the joints for the Foundation Mat. Each of the 3 groups has an associated stiffness assigned to the connecting link elements. The contact area of each group is multiplied by the soil stiffness (Modulus of subgrade reaction, k/ft^3) in order to determine the effective stiffness (k/ft) for both the vertical and horizontal directions. Table 6.1.1 displays the joint groups and associated contact areas and Table 6.2.1 provides the stiffness associated with each of the two-joint link elements.

The SAP2000 (Reference 2.2.11) two-joint link elements were used to model the soil stiffness in both the vertical and horizontal directions (Figure 6.1.3).

The first layer of joints used for the two-joint link element exists at the bottom of the AP Foundation Mat. The second layer is created by replicating the joints on the AP Foundation Mat at an arbitrary vertical distance of −17 ft, placing them at an elevation of −20 ft.

The joints on the AP Foundation Mat mesh (Figure. 6.1.2), elevation −3 ft, were assigned labels based on the group associated with the specific contact area. The labels for the AP Foundation Mat joints are labeled as Bcj, Bej and Bij, where “B” defines the joint as located on the Basemat, “c, e, and i ” defines the joints at corner, edge and inside respectively. The joints modeled at elevation −20 ft share the same alphanumeric labeling except the “B” is replaced with “G”, defining the joint location as ground. The two-joint link elements that are used to model the soil stiffness are connected between a joint on the AP Foundation Mat, elevation −3 ft and the corresponding joint on the ground, elevation −20 ft. The links modeled between the two joints are labeled in a similar fashion, using “L”.

The connectivity and labeling of the interior two-joint link elements is as follows:

AP Basemat Joint Label	Link Element Label	AP Ground Joint Label
Bi1	Li1	Gi1

Concrete material properties used in this finite model and listed in section 6.6 of this calculation are taken from *Project Design Criteria* (Reference 2.2.7, Section 4.2.11.6.6).

The SAP2000 (Reference 2.2.11) model database file is included in Attachment A.

SAP2000 (Reference 2.2.11) graphics show the model configuration. The isometric view of foundation mat elements is included in Figure 6.1.1. The Foundation mat finite element mesh is shown in Figure 6.1.2, and the elevation of Link elements are shown in Figure 6.1.3.

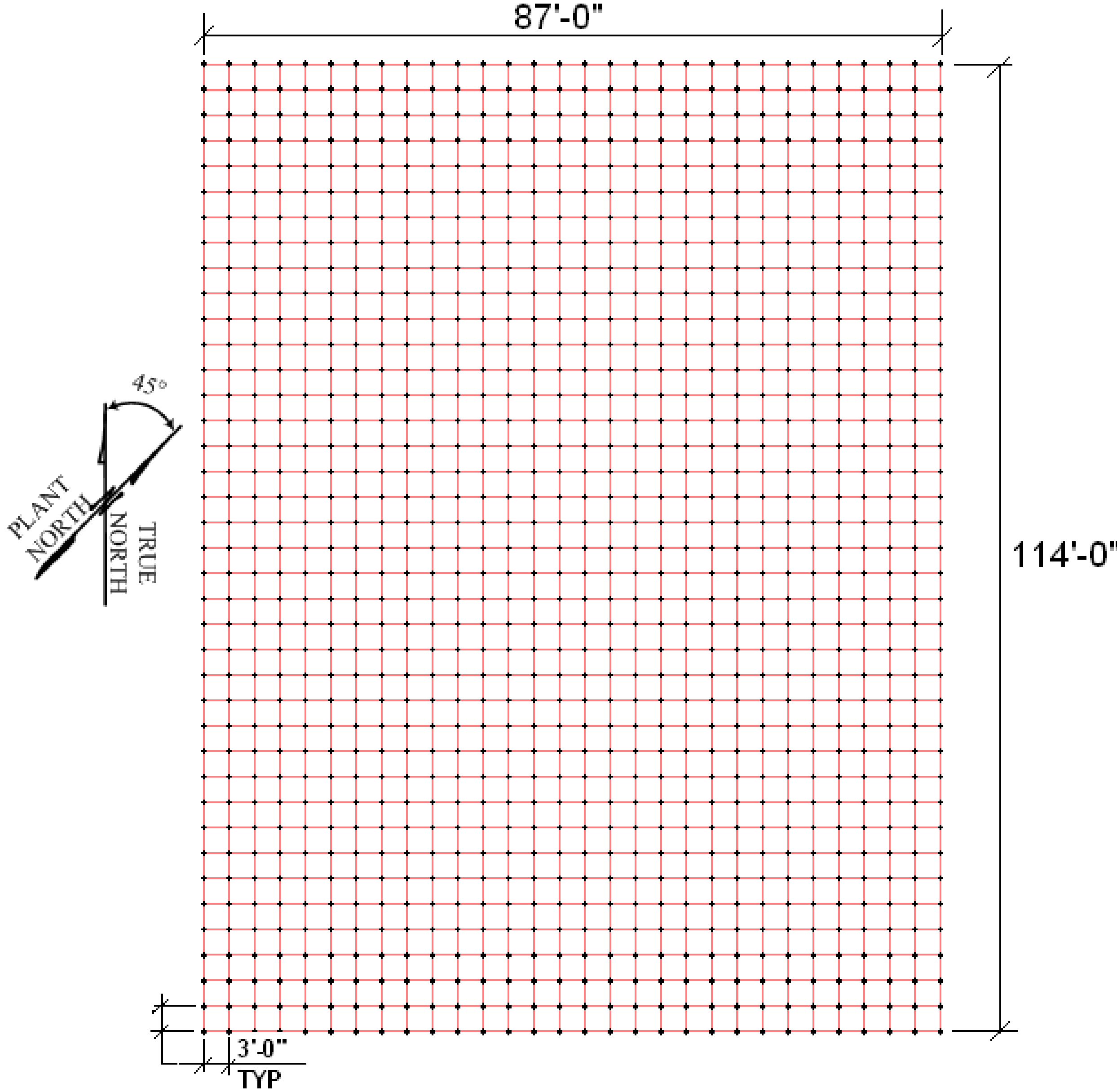
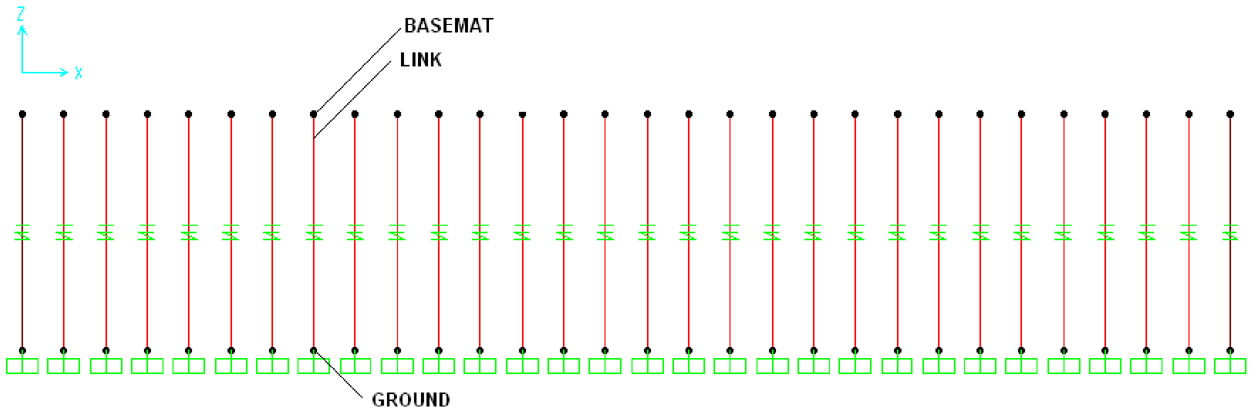


Figure 6.1.2 Foundation Mat Finite Element Mesh



Elevation View

Figure 6.1.3 Link Elements

6.2 SOIL STIFFNESS MODELING

As stated in Section 6.1, the boundary conditions for the AP Foundation Mat were modeled using the SAP2000 (Reference 2.2.11) two-joint link element. The spring stiffness values are based on the minimum values of Modulus of sub-grade reaction (Reference 2.2.16, Table 2-2). The Foundation Mat finite element model will have a support point located at each node of the shell element mesh. Therefore, the global spring must be converted into individual springs applied to each node of the shell element mesh, based on the contact area of the joint. This section contains the joint spring calculation.

The Modulus of Sub-grade Reaction (global spring constants) (units of kips/ft^3) from the supplement soils report (Reference 2.2.16, Table 2-2) for alluvium (Assumption 3.1.2) are listed below.

Soil Spring Coordinate System	Value from Table 2-2, Reference 2.2.16	Multiplication factor used** (for all cases)	Design Value
KX (Horizontal)	104 kcf	1	104 kcf
KY (Horizontal)	104 kcf	1	104 kcf
KZ (Vertical)	155 kcf	1	155 kcf

**Based on *Supplemental Soils Report* (Reference 2.2.16, Table 2-2) the modeling of short term static loading associated with soil stiffness may be double the assigned value shown above. For static (long term) load combinations 1 thru 4, use multiplication factor of 1 and also for seismic (short term) loading combinations 5 thru 16, use multiplication factor of 1 to be on the side of conservatism.

There are 3 different spring values calculated to represent both vertical and horizontal stiffness of the underlying soil. These are based on the 3 different contact areas (see Table 6.1.1) for all 1170 joints that make up the AP Foundation Mat. The areas (ft^2) are multiplied by the modulus of sub-grade reaction (k/ft^3) to determine effective stiffness (k/ft). Table 6.2.1 lists the stiffness associated with each of the two-joint link elements used in SAP2000 (Reference 2.2.11) modeling.

Table 6.2.1 Applied Spring Stiffness for Each Defined Link Element

Link Definition Name	Links in Category	Vertical Stiffness (k/ft)	Horizontal Stiffness (k/ft)
Group A (100% Link)	Li1 - Li1036	155 kcf x 9.0 ft^2= 1395 k/ft	104 kcf x 9.0 ft^2= 936 k/ft
Group B (50% Link)	Le1 - Le130	697.5	468
Group C (25% Link)	Lc1 - Lc4	348.75	234

6.3 LOADS

6.3.1 Basic Loads

Dead Load (D):

Self-weight of concrete foundation mat is considered as dead load.

Weight of 3 ft thick foundation mat (**D**) = 0.15 $k/ft^3 \times 3$ ft = **0.45 k/ft^2** (see Figures 6.3.1 and 6.3.2)

The other dead load includes weight of aging overpack (governs), vertical dual-purpose canister (DPC) aging overpack, site transporter, and Horizontal Aging Module (HAM).

A. Aging Overpack (Ref. 2.2.17)

Normal Load, Maximum loaded weight of Aging Overpack = W_{cask} = 250 ton = 500 kips (Reference 2.2.17, Note 2). Dimensions of the Aging Overpack are 12 ft. diameter and 22 ft. high (Ref. 2.2.17).

Load is distributed to 12 elements, each 3 ft by 3 ft to represent approximate circular loading area ($\pi*d^2/4$ = 113 ft^2) of 12 ft diameter cask. Total area of 12 elements = 12*9 = 108 ft^2 (Figures 6.3.1 and 6.3.2; Assumption 3.1.1)

Therefore, Uniform load on foundation for (**CASKL**) = W_{cask}/12 element (3 ft by 3 ft each) = 500/108 = **4.63 kip/ft^2** (Figures 6.3.1 and 6.3.2)

B. Vertical DPC Aging Overpack (Reference 2.2.18, Note 3)

Fully loaded weight = 250 tons maximum, same as Aging Overpack.

C. Maximum empty weight of site transporter (TRANSU) = 150 tons = 300 kip (Reference 2.2.5, Section 10.2.1.5). Load is distributed to total 12 elements of equal areas, 6 elements on each side; each element is 3 ft by 3 ft at 15 ft spacing to represent approximate actual loading contact area. This load is applied at center and edge of pad (See Figures 6.3.1 and 6.3.2).

Therefore, loaded weight of site transporter (**TRANSL**) = 300+500 = 800 kip/ (6 element × 3’×3’×2 sides, Assumption 3.1.1) = 7.41 kip/ft^2**, Use 8.0 kip/ft^2** (For location, see Figure 6.3.1 for transporter at edge and Figure 6.3.2 for transporter at center)

D. Horizontal Aging Module (Ref. 2.2.19)

Calculate weight of each HAM

Estimated (concrete) door weight = 7’ x 7’ x 1.75’ thick x 0.15 kcf = 12.9, say 13.0 kips

Horizontal STC (Payload) = 125 tons = 250.0 kips

Total volume of HAM concrete = 21’ × 21’ × 8’-6” = 3,748.5 ft^3

Volume of STC = π r^2 h = π 4.25^2 × 21’ = 1,191.65 ft^3

Net volume = 3,748.5 ft^3 - 1,191.65 ft^3 = 2,556.9 ft^3

Weight of HAM = 0.15 k/ft^3 × 2,556.9 ft^3 = 383.5 kips/HAM

Loaded weight of HAM = 13 + 250 + 383.5 = **646.5 kips**

Number of HAMs/ pad = 15

Total weight of HAMs/pad = 646.5 kips × 15 = 9697.5 kips

Weight of 3’ concrete shield wall/pad = 0.15 k/ft^3 (3’ × 21’ x 133.5’ + 3’ × 21’ × 21’ × 2 (side walls)) 1658.5 kips

Weight of HAMs/pad = 9697.5 + 1658.5 = 11,356 kips

Contact area of HAMs/pad = 127.5’ × 21’ = 2677.5 ft^2

Net pressure on pad surface = 11,356 kips / 2677.5 ft^2 = **4.24 kips/ ft^2**

E. Horizontal Transfer Trailer (Reference 2.2.21) and Horizontal STC (Reference 2.2.22)

Estimated loaded weight = 165 tons = 330 kips (Reference 2.2.21, note 2) < 800 kips (TRANSL)

F. Cask Tractor (Reference 2.2.23)

Cask Tractor will be on site but not on HAMs pad at any time. Not considered.

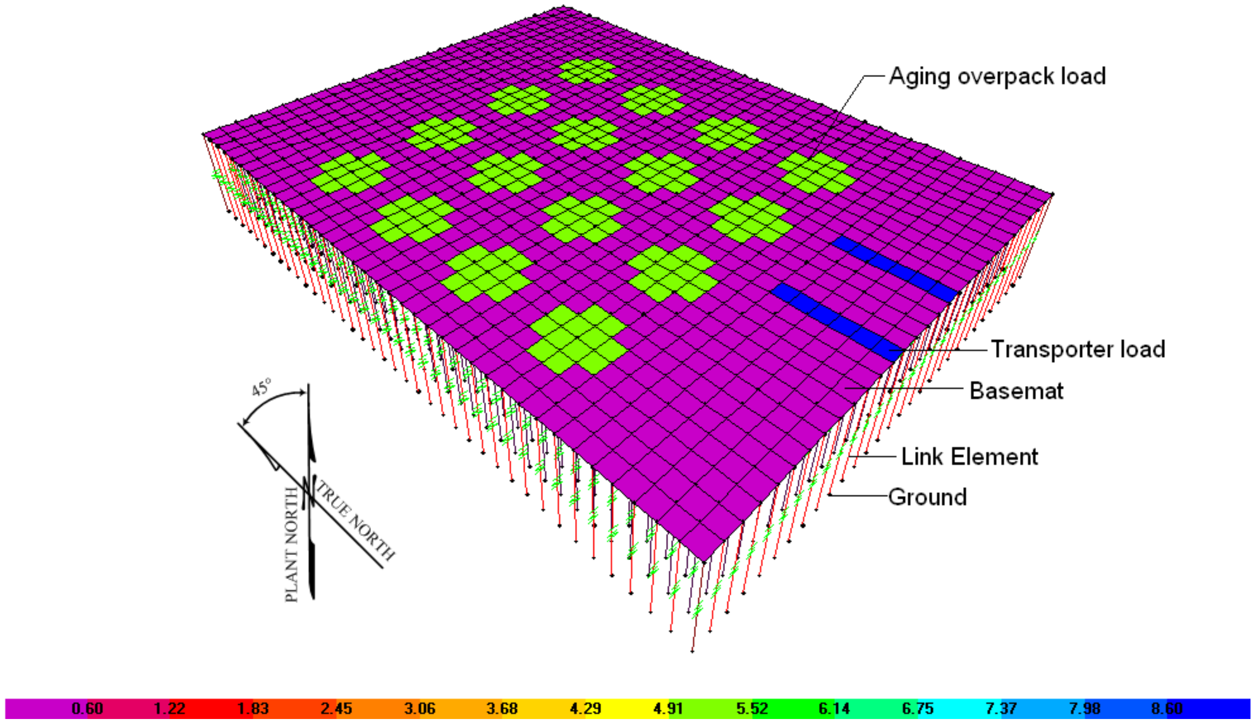


Figure 6.3.1 Location of Loaded Cask and Loaded Transporter at Center

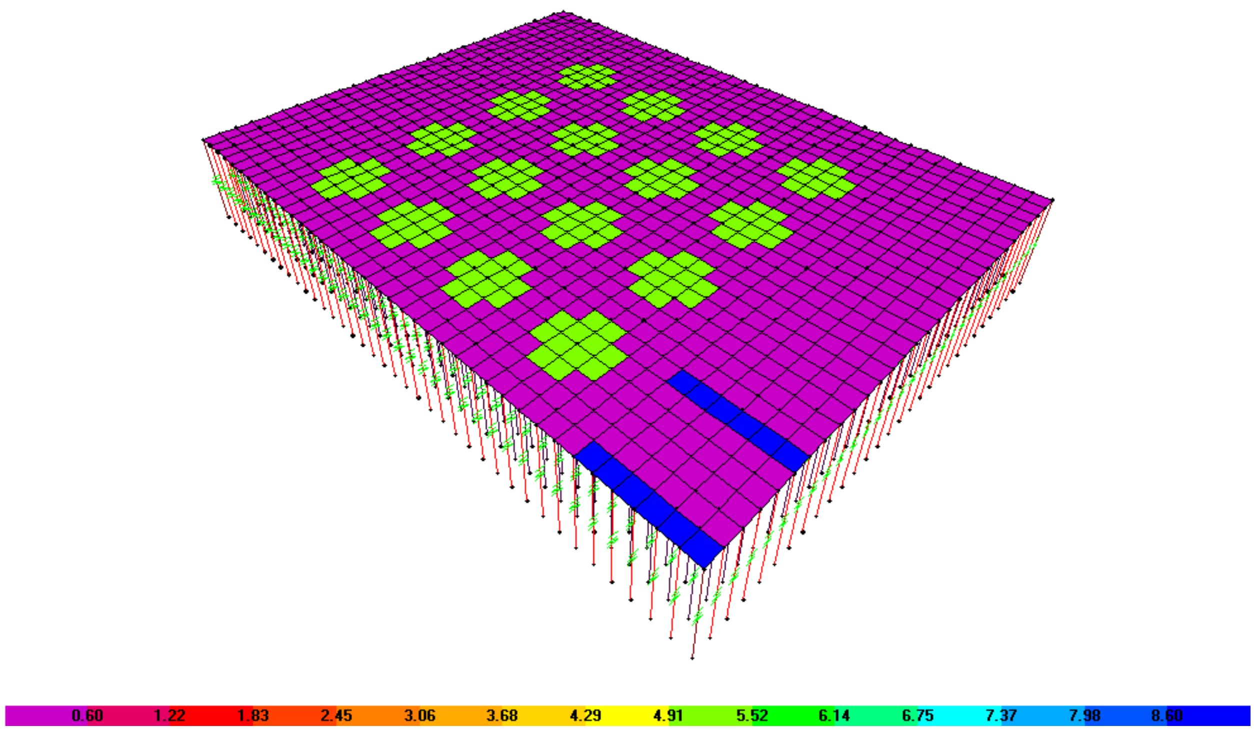


Figure 6.3.2 Location of Loaded Cask and Loaded Transporter at Edge

Live Loads (L)

The live loads are those produced by the use of the facility.

A. Mat live loads include a uniform load of 150 psf on entire surface of mat. Minimum uniform live load for light storage warehouse is 125 psf in accordance with ASCE 7-98 (Reference 2.2.13, Table 4-1), but use 150 psf to be conservative.

Use, (L) = 0.15 k/$\mathbf{ft^2}$

B. Snow Load (S):

The slab will be designed for a maximum monthly snowfall of 6.6" (Reference 2.2.7, Section 6.1.1). The snow load magnitude, based on the provisions of ASCE 7-98 (Reference 2.2.13), is determined to be 3.78 psf (see below).

$P_f = 0.7\ Ce\ Ct\ I\ Pg$ (Eq.7-1, Reference 2.2.13)

Ce = 0.9 (Table 7-2, Reference 2.2.13, Use highest value to be conservative)

Ct = 1.0 (Table 7-3, Reference 2.2.13, for all structures)

I = 1.2 (Table 7-4, Reference 2.2.13, Use highest value to be conservative)

Pg = 5 psf (Fig. 7-1, Reference 2.2.13)

Snow Load, P_f = 3.78 psf, very small. The 150 psf (mat live load) is sufficient to account for snow load.

C. Ash Load:

Structural loading shall take into account volcanic ash fall, which is 4 in., with a density of 63 lb/ft^3 (Reference 2.2.7, Section 6.1.11).

Design Ash Load = 4 in. /12*63 = 21 psf < 150 psf (mat live load), therefore, **not governing**

6.3.2 Extreme Loads

Seismic Loads (E)

The AP shall be designed for loading conditions associated with a DBGM-2 seismic event in accordance with Table 5-2 of SADA document (Ref. 2.2.12).

Mass source for dynamic seismic loading is based on Dead Load + 0.25 × Live Load (Reference 2.2.12, Section 8.3.1).

For concrete foundation mat and Site Transporter:

- For appropriate response spectra refer to Reference 2.2.24 for 5×10^{-4} site D/E horizontal spectra and vertical spectra. The seismic data in Reference 2.2.24 have been entered into the Technical Data Management Database, but they are unqualified and are not currently included on an interface exchange drawing. Completion of these activities is being tract in the document Input Reference System database via TBV-8980.

- Horizontal acceleration = 0.45g, Vertical acceleration = 0.32g (Assumption 3.1.4)

For Aging Overpack:

- Horizontal acceleration = 1.021g say 1.03g, not to exceed coefficient of friction = 0.35 (Ref. 2.2.26, Chapter 1.8).
- Vertical acceleration = 0.716g.

The above values of horizontal and vertical accelerations are obtained from Attachment D, corresponding to the rotating stability at approximately 0.03 degrees, for the DBGM-2 case with 7% damping.

Equivalent static seismic forces for design

Under DBGM-2, the demand never reaches the capacity (Attachment D); therefore, the cask does not lift up and it is in incipient sliding condition. This condition occurs when the horizontal force applied to the cask is equal to the frictional resistance force and resulting in forces on foundation as shown in Figure 6.3.3.

D = 0.45 k/ft^2, Therefore,

HX = 0.45 × 0.45 = 0.20 k/ft^2, HY = 0.45 × 0.45 = 0.20 k/ft^2 & VZ = 0.32 × 0.45 = 0.14 k/ft^2

0.25 L = 0.25 × 0.15 k/ft^2 = 0.04 k/ft^2, Therefore,

HX = 0.45 × 0.04 = 0.02 k/ft^2, HY = 0.45 × 0.04 = 0.02 k/ft^2 & VZ = 0.32 × 0.04 = 0.01 k/ft^2

D + 0.25 L

HX_1 = 0.20 + 0.02 = 0.22 k/ft^2, HY_1 = 0.20 + 0.02 = 0.22 k/ft^2 & VZ_1 = 0.14 + 0.01 = 0.15 k/ft^2

Aging Overpack, CASKL = 4.63 k/ft^2, Therefore,

HX_2 = 0.35 × 4.63 = 1.62 k/ft^2, HY_2 = 0.35 × 4.63 = 1.62 k/ft^2 & VZ_2 = 0.716 × 4.63 = 3.32 k/ft^2

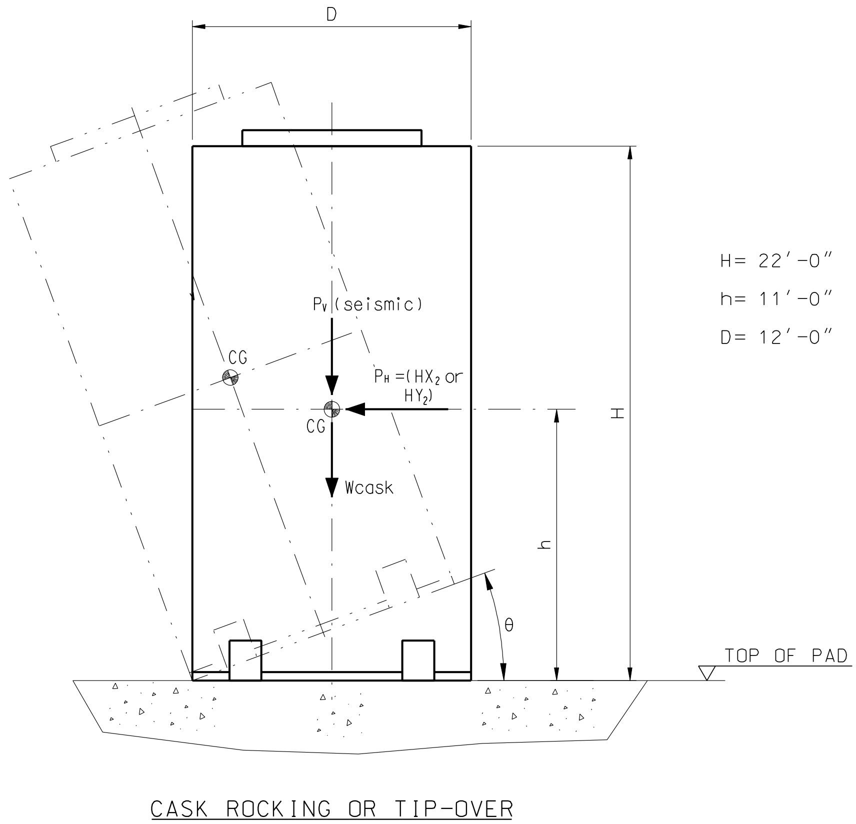
Pv (seismic) = CASKL x a_v = 500 × 0.716 (vertical spectra for 7% damping)

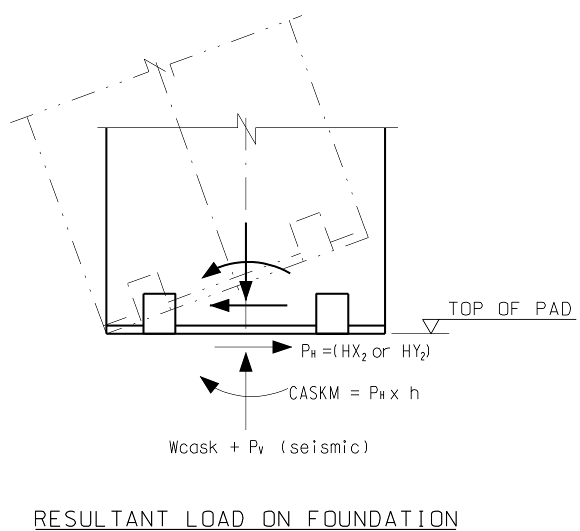
= 358 kips (Seismic vertical downward).

Horizontal seismic acceleration acting at center of gravity of cask is 1.03. Horizontal force is limited to coefficient of friction between concrete and steel (0.35) x weight of cask for sliding force and moment on foundation.

Moment on foundation due to horizontal force on cask, CASKM = (0.35 × 500) k × 11 ft = 1925.00 k-ft

Moment on foundation is applied in proportion to equivalent distributed area as shown in Figure 6.3.4 and Table 6.3.1.





Per Attachment D, DBGM-2, 10 % Damping; Conclusion: cask does not lift up.

Figure 6.3.3 Cask Forces on Foundation

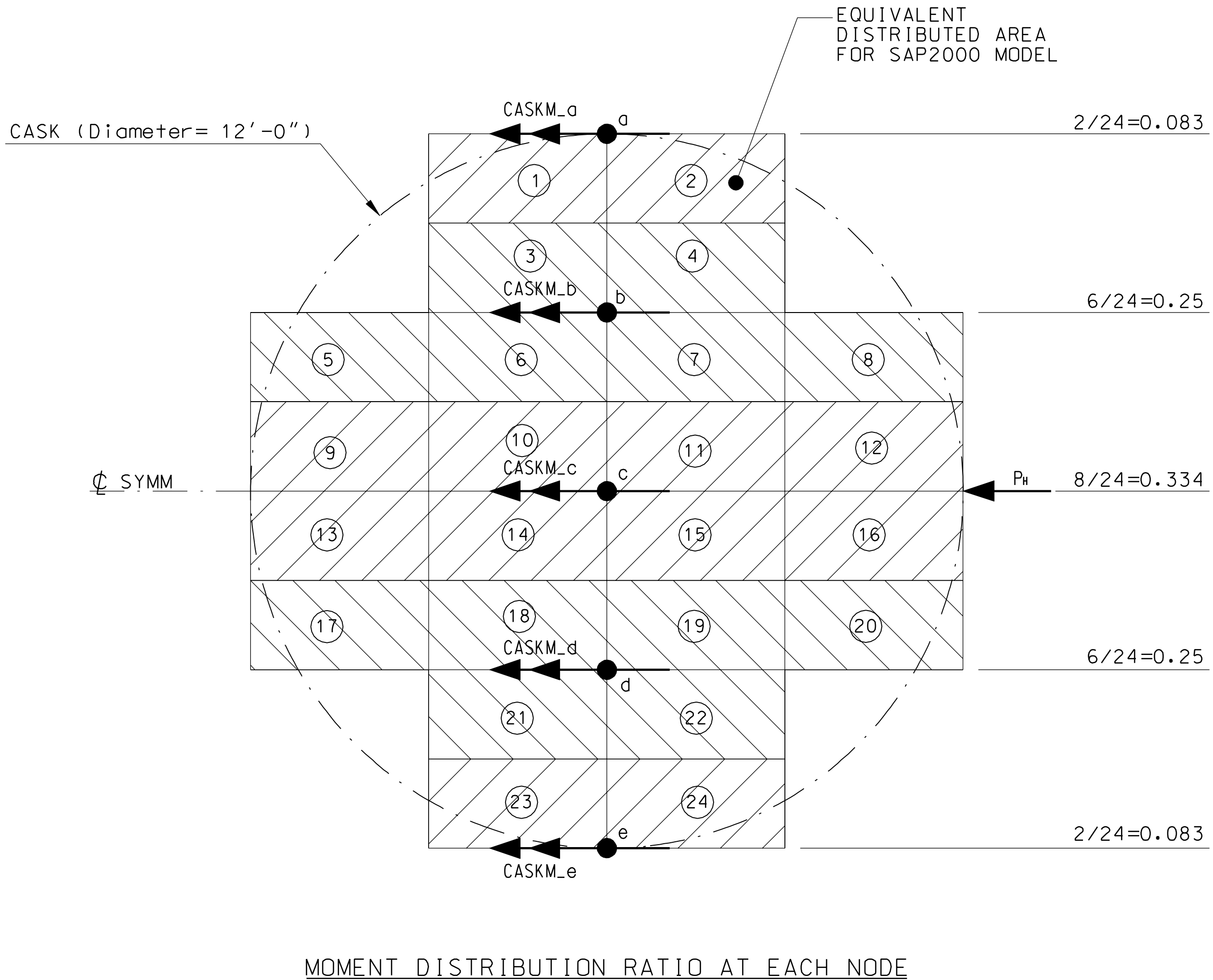


Figure 6.3.4 Cask Over Turning Moment Distribution

Table 6.3.1 Distribution of Moment at each Cask for SAP2000[a] Model

Node	Load Case	Total Moment	Distribution Ratio	Applied Moment
a	CASKM_a	1925 k-ft	0.083	159.80 k-ft
b	CASKM_b	1925 k-ft	0.250	481.25 k-ft
c	CASKM_c	1925 k-ft	0.334	642.90 k-ft
d	CASKM_d	1925 k-ft	0.250	481.25 k-ft
e	CASKM_e	1925 k-ft	0.083	159.80 k-ft
			Total Moment =	1925 k-ft

See Figure 6.3.3 and 6.3.4.

[a] Reference 2.2.11

TRANSL _Center or TRANSL _Edge = 8.00 k/ft^2, Therefore,

HX_Center or HX_Edge = 0.45 × 8.00 = 3.6 k/ft^2, HY_Center or HY_Edge = 0.45 × 8.00 = 3.6 k/ft^2 & VZ_Center or VZ_Edge = 0.32 × 8.00 = 2.56 k/ft^2

Wind Load (W)

Basic wind Speed, V = 90 mph (Reference 2.2.7, Sec. 6.1.3)

Wind Pressure = 19.17 psf (Reference 2.2.15, page A23)

Base shear = V (wind velocity) D (cask diameter) H (cask height) = 19.17 psf × 12 ft × 22 ft = 5,061 lbs = 5.061 kips.

Tornado Wind Loads (W_t)

Tornado wind speed, Vt = 189 mph (Reference 2.2.7, Section 6.1.4)

Tornado Wind Pressure P_{wt}= 19.17 psf × $(189/90)^2$ = 84.54 psf

Base shear = P_{wt} D H = 84.54 psf × 12 ft × 22 ft = 22,318 lbs = 22.32 kips.

Now, base shear due to seismic load = 500 × 0.35 = 515 kip > 22.32 kips > 5.061 kips

By inspection wind and tornado wind load is less than seismic load, therefore, no further checking required for wind or tornado loads.

6.4 LOAD COMBINATIONS

Since soil bearing pressures are based on un-factored loads and concrete design is based on factored loads, the following un-factored and factored load combinations are considered in the analysis of the slab; these are based on those given in Section 4.2.11.4.5 of the PDC (Reference 2.2.7, Section 4.2.11.4.5):

Load Combination	Limit	PDC, Section 4.2.11.4.5, Load Combination Number
1. D + S + L	Soil [(1)]	13, Use this combination

2. D + S + L + W_t	Soil	17, Not governing
3. D + W	Soil	Not governing
4. 1.4D + 1.7S + 1.7L	U (2)	2, Use this combination
5. 1.4D + 1.7S + 1.7L + 1.7W	U	4, not governing
6. D + L + Wt	U, Soil	10, not governing
7. D + Wt	U, Soil	See Section 4.2.11.4.4-B, not governing
8. D + L + E	U, Soil	9, Use this combination
9. 0.9D + E	U, Soil	See Section 4.2.11.4.4-B, not governing

NOTES: 1. Soil – allowable soil bearing strength and/or structure stability; see Section 6.5.2.
2. U – required section strength based on Ultimate Strength Design (USD) using the provisions of ACI 349-01 (Reference 2.2.8).

Loading Combination based on 100-40-40 component factor method (Reference 2.2.9, Section 3.2.7.1.2 and Eq. 3.2-26)

The forces and moments in the Foundation mat will be determined based on a combination of the three global directions considered in the seismic analysis, which are HX, HY, and VZ as well as the self-weight of the structure. HX (east-west) and HY (north-south) represent both orthogonal horizontal directions and VZ represents the vertical direction. Self-weight is in the negative Z direction. To account for non-orthogonal seismic effects, the loading combinations considered are based on the 100-40-40-component factor method from Section 3.2.7.1.2, ASCE 4-98 (Reference 2.2.9), which uses 100% seismic loading in one direction, combined with 40% seismic in the remaining two directions. The 100-40-40-component factor method (Reference 2.2.9) yields three basic load combinations:

± 1.0 HX $\pm$ 0.4 HY $\pm$ 0.4 VZ
± 0.4 HX $\pm$ 1.0 HY $\pm$ 0.4 VZ
± 0.4 HX $\pm$ 0.4 HY $\pm$ 1.0 VZ

Manipulating the above combinations (using the plus and minus signs) yields 24 loading permutations:

1:	+ 1.0	HX	+ 0.4	HY	+ 0.4	VZ
2:	+ 1.0	HX	+ 0.4	HY	- 0.4	VZ
3:	+ 1.0	HX	- 0.4	HY	+ 0.4	VZ
4:	+ 1.0	HX	- 0.4	HY	- 0.4	VZ
5:	- 1.0	HX	+ 0.4	HY	+ 0.4	VZ
6:	- 1.0	HX	+ 0.4	HY	- 0.4	VZ
7:	- 1.0	HX	- 0.4	HY	+ 0.4	VZ
8:	- 1.0	HX	- 0.4	HY	- 0.4	VZ
9:		HX	+ 1.0	HY		VZ
10:		HX	+ 1.0	HY		VZ
11:		HX	+ 1.0	HY		VZ

12:	- 0.4	HX	+ 1.0	HY	- 0.4	VZ
13:	+ 0.4	HX	- 1.0	HY	+ 0.4	VZ
14:	+ 0.4	HX	- 1.0	HY	- 0.4	VZ
15:	- 0.4	HX	- 1.0	HY	+ 0.4	VZ
16:	- 0.4	HX	- 1.0	HY	- 0.4	VZ
17:	+ 0.4	HX	+ 0.4	HY	+ 1.0	VZ
18:	+ 0.4	HX	- 0.4	HY	+ 1.0	VZ
19:	- 0.4	HX	+ 0.4	HY	+ 1.0	VZ
20:	- 0.4	HX	- 0.4	HY	+ 1.0	VZ
21:	+ 0.4	HX	+ 0.4	HY	- 1.0	VZ
22:	+ 0.4	HX	- 0.4	HY	- 1.0	VZ
23:	- 0.4	HX	+ 0.4	HY	- 1.0	VZ
24:	- 0.4	HX	- 0.4	HY	- 1.0	VZ

The AP Foundation mat is almost symmetrical with respect to global X-axis. Thus, the foundation pressure at the northeast corner will be same as the foundation pressure at the southeast corner. Similarly, the maximum foundation pressure at the northwest corner will be same as the pressure at the southwest corner. Therefore, 12 combinations with negative HY force component will be similar to the twelve combinations with positive HY force components. This results in following 12 load combinations to provide the required foundation load for design.

1:	DL	+ 1.0	HX	+ 0.4	HY	+ 0.4	VZ
2:	DL	+ 0.4	HX	+ 1.0	HY	+ 0.4	VZ
3:	DL	+ 0.4	HX	+ 0.4	HY	+ 1.0	VZ
4:	DL		HX	+ 0.4	HY		VZ
5:	DL		HX	+ 1.0	HY		VZ
6:	DL		HX	+ 0.4	HY		VZ
7:	DL		HX	+ 0.4	HY		VZ
8:	DL		HX	+ 0.4	HY		VZ
9:	DL		HX	+ 1.0	HY		VZ
10:	DL	- 0.4	HX	+ 0.4	HY	+ 1.0	VZ
11:	DL	- 1.0	HX	+ 0.4	HY	+ 0.4	VZ
12:	DL	- 0.4	HX	+ 1.0	HY	+ 0.4	VZ

As Aging Overpacks are not anchored down to foundation, only downward vertical (-Z direction) load will impact the mat design. Thus eliminating positive Z direction loading results in the following 6 load combinations for mat design.

1:	DL	+ 1.0	HX	+ 0.4	HY	- 0.4	VZ
2:	DL	+ 0.4	HX	+ 1.0	HY	- 0.4	VZ
3:	DL	+ 0.4	HX	+ 0.4	HY	- 1.0	VZ
4:	DL	- 0.4	HX	+ 0.4	HY	- 1.0	VZ
5:	DL	- 1.0	HX	+ 0.4	HY	-0.4	VZ
6:	DL	- 0.4	HX	+ 1.0	HY	- 0.4	VZ

Load Combination for final run:

Earthquake Load:

Use 0.45 in horizontal X and Y direction for concrete mat and transporter, and 0.35 (Coefficient of friction) in horizontal X and Y direction for cask and 0.32 vertical Z direction Gravity Multipliers for concrete mat and transporter and 0.716 vertical Z direction Gravity Multipliers is applied to each cask to get forces to be used in calculating factored seismic (1, 0.4, 0.4) combination.

HX = 0.45 (D + 0.25* L) + 0.35(CASKL + CASKLM_a to CASKLM_e)
HX_Center = 0.45 (TRANSL_Center)

HX_Edge = 0.45 (TRANSL_Edge)

HY = 0.45 (D +0.25* L) + 0.35(CASKL + CASKLM_a to CASKLM_e)

HY_Center = 0.45 (TRANSL_Center)

HY_Edge = 0.45 (TRANSL_Edge)

VZ = 0.32(D + 0.25* L) + 0.716(CASKL)

VZ_Center = 0.32 (TRANSL_Center)

VZ_Edge = 0.32 (TRANSL_Edge)

Analysis Cases (Load Combinations):

1) DL _Center = D + L + CASKL + TRANSL_Center

2) DL _Edge = D + L + CASKL + TRANSL_Edge

3) DL(Factored) _Center = 1.4D + 1.7(L + CASKL + TRANSL_Center) (Cask and Transporter are considered as Live Load)

4) DL(Factored) _Edge = 1.4D+ 1.7(L+CASKL+TRANSL_Edge)

For seismic forces in load combinations 5 thru 16, Cask and Transporter are considered as Dead Load to be conservative.

5)	DL_Center	1 (HX + HX_Center)	0.4 (HY + HY_Center	-0.4 (VZ + VZ_Center)
6)	DL_ Center	0.4 (HX + HX_Center)	1 (HY + HY_Center)	-0.4 (VZ + VZ_Center)
7)	DL_ Center	0.4 (HX + HX_Center)	0.4 (HY + HY_Center)	-1 (VZ + VZ_Center)
8)	DL_ Center	-0.4 (HX + HX_Center)	0.4 (HY + HY_Center)	-1 (VZ + VZ_Center)
9)	DL_ Center	-1 (HX + HX_Center)	0.4 (HY + HY_Center)	-0.4 (VZ + VZ_Center)
10)	DL_ Center	-0.4 (HX + HX_Center)	1 (HY + HY_Center)	-0.4 (VZ + VZ_Center)
11)	DL_ Edge	1 (HX + HX_Edge)	0.4 (HY + HY_Edge	-0.4 (VZ + VZ_Edge)
12)	DL_ Edge	0.4 (HX + HX_Edge)	1 (HY + HY_Edge)	-0.4 (VZ + VZ_Edge)
13)	DL_ Edge	0.4 (HX + HX_Edge)	0.4 (HY + HY_Edge)	-1 (VZ + VZ_Edge)
14)	DL_ Edge	-0.4 (HX + HX_Edge)	0.4 (HY + HY_Edge)	-1 (VZ + VZ_Edge)
15)	DL_ Edge	-1 (HX + HX_Edge)	0.4 (HY + HY_Edge)	-0.4 (VZ + VZ_Edge)
16)	DL_ Edge	-0.4 (HX + HX_Edge)	1 (HY + HY_Edge)	-0.4 (VZ + VZ_Edge)

DL = Non-seismic loads which include mat dead loads and 100% of all live loads.

NOTE: Live load considered in seismic loads is 25% of design live load (Reference 2.2.12, Section 8.3.1)

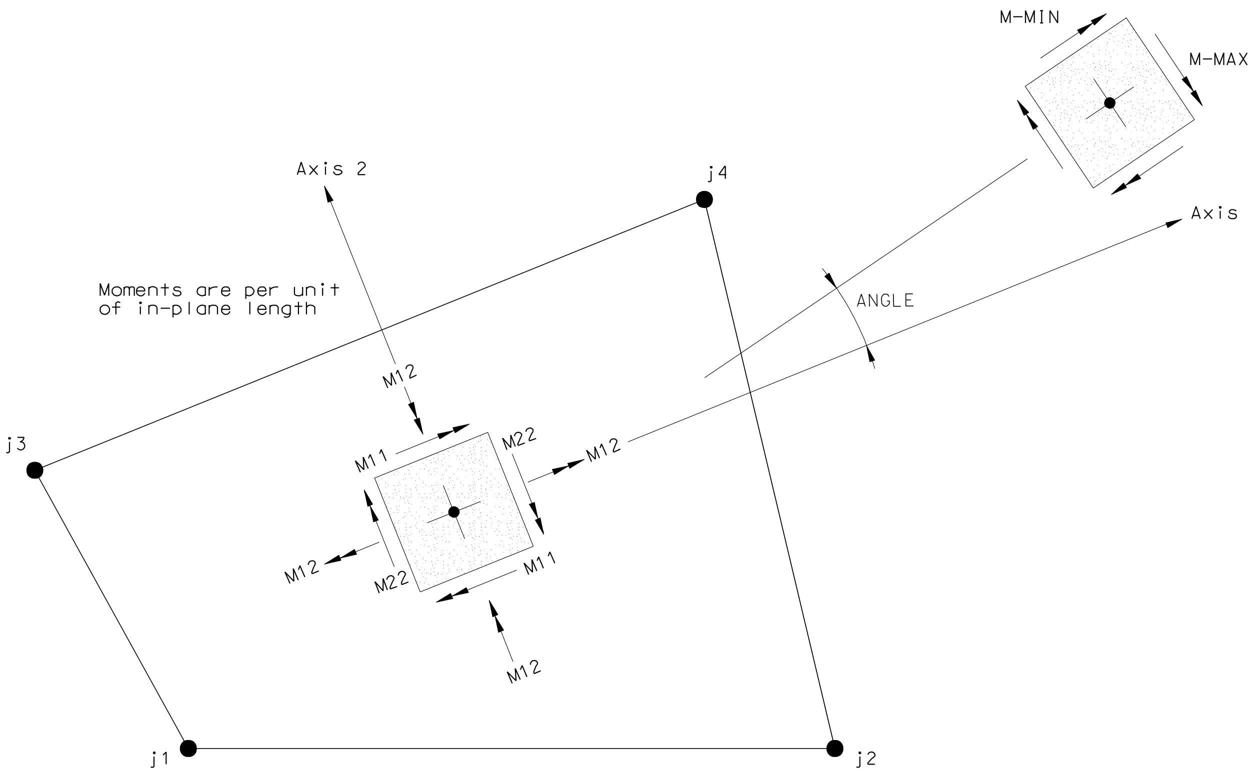
Notations used in this calculation and SAP2000 (Reference 2.2.11) are listed below.

Global Directions	This calculation
East-West	HX
North-South	HY
Vertical	VZ

6.5 SAP2000 ANALYSIS RESULTS

6.5.1 Bending Moments and Shear Forces in Foundation Mat

Stress contour plots for the Foundation Mat are included in Attachment C. The contour plots represent the bending moments M11 and M22, twisting moment M12, and shear forces V13 and V23. For information on the definitions of M11, M22, M12, V13, and V23, refer to Figure 6.5.1 and Figure 6.5.2.



Axis 3 is out of the paper

Figure 6.5.1 Shell Element Bending and Twisting Moments

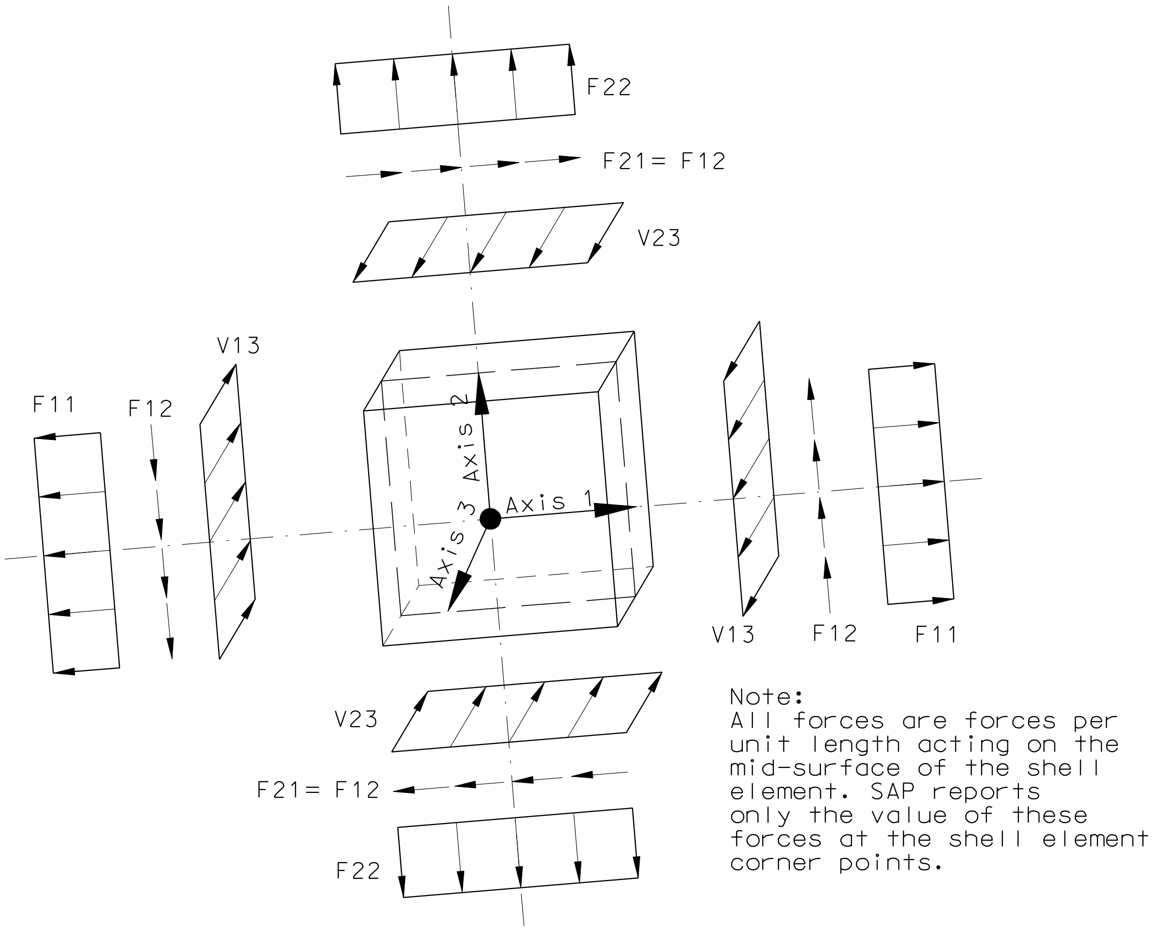


Figure 6.5.2 Shell Element Membrane and Shear Forces

SAP2000 (Reference 2.2.11) stress averaging at joints is used to smooth the contour plots. The maximum moment and shear values are derived graphically by visual inspection of the force contours (See Assumption 3.2.1).

6.5.2 Maximum Bearing Pressure on Foundation Mat

The maximum bearing pressure on the mat is determined by dividing the link element reaction force by the contact area of the link. The maximum bearing pressure occurs at (link # Le1, load combination 14, Figure 6.5.3) the south-west corner of the mat is under load combination 14. The maximum (ultimate) bearing pressure on the mat = 18.516 kips / 4.5ft^2 = 4.11 kips per square foot, which is less than (ultimate) bearing capacity of 50 ksf for large foundation mat (Reference 2.2.12, Section 6.2.3). From output for Link Element Deformations, maximum deformation is 0.026546 ft × 12 in. = 0.319 inch for Link #.Le1 (south-west corner) for load combination 14.

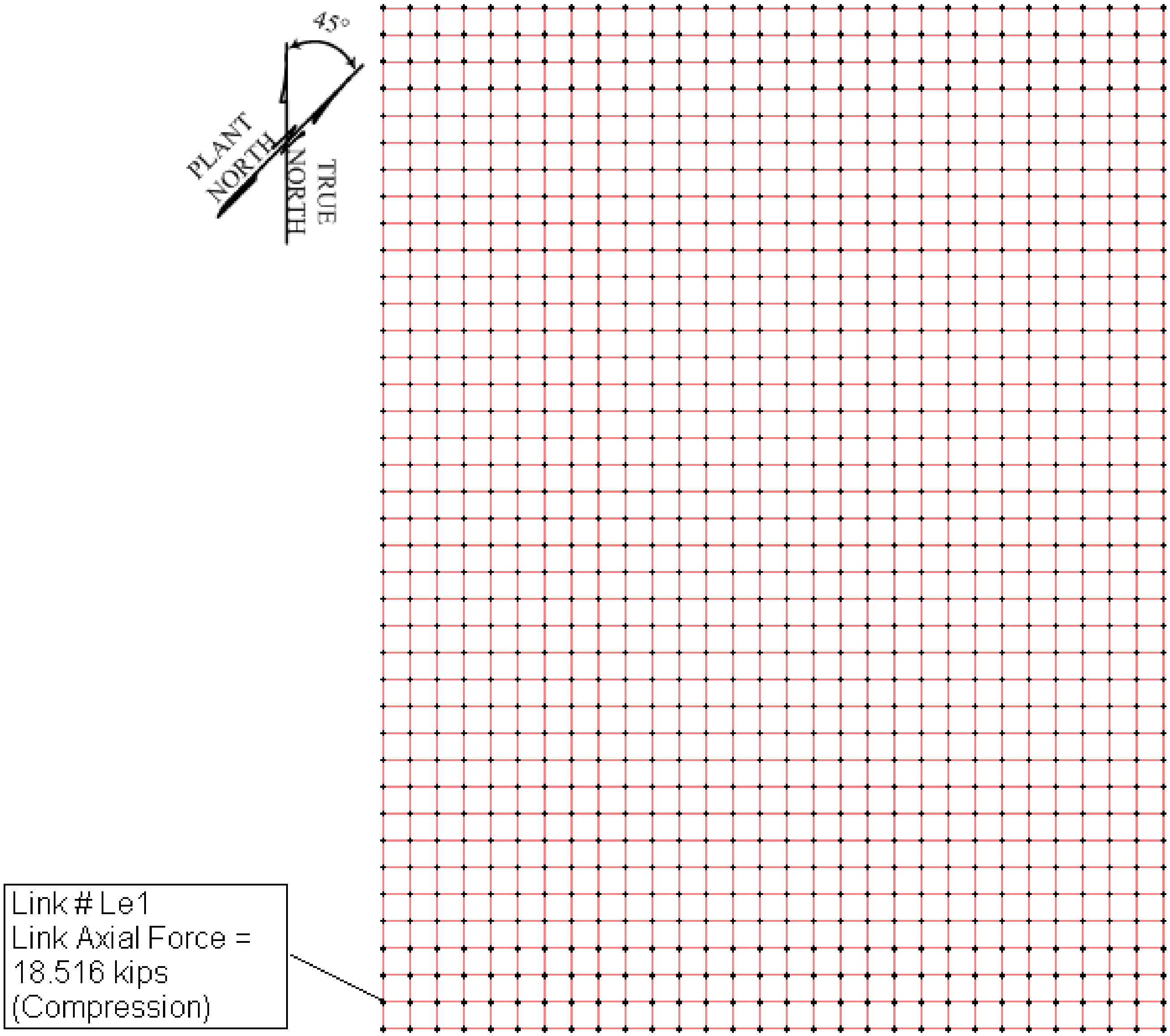


Figure 6.5.3 Location of Maximum Link Axial Force

6.6 REINFORCING DESIGN

(The values listed in Table 6.6.1 are minimum and maximum moments and shear forces from SAP2000 (Reference 2.2.11) contour plots presented in Attachment C)

Table 6.6.1 Moments and Shear Forces

(All values are for per foot width only)

Analysis Case	M11(k-ft)		M22 (k-ft)		M12 (k-ft)		V13 (kip)	V23 (kip)
	Negative	Positive	Negative	Positive	Negative	Positive		
Comb1	21.531	41.613	25.312	38.254	11.329	10.999	13.673	13.704
Comb2	29.644	35.556	27.052	38.647	21.728	11.099	13.906	14.447
Comb3	36.603	70.742	43.031	65.032	19.260	18.698	23.244	23.297
Comb4	50.396	60.446	45.989	65.700	36.938	18.868	23.640	24.560
Comb5	77.791	135.243	44.178	97.015	26.727	29.317	27.797	22.485
Comb6	42.523	90.213	71.325	138.213	25.962	27.422	20.810	29.932
Comb7	46.371	96.328	49.751	103.502	21.168	15.117	25.364	27.879
Comb8	40.528	89.795	51.506	103.916	19.361	18.834	24.354	27.870
Comb9	87.885	139.269	46.229	96.845	31.289	31.181	30.329	22.435
Comb10	37.752	87.434	72.604	138.189	24.628	27.968	21.624	29.928
Comb11	76.548	135.533	44.738	97.088	37.654	29.386	29.096	22.634
Comb12	41.729	90.052	72.447	138.905	34.654	29.735	20.289	30.780
Comb13	44.376	95.968	49.655	103.227	33.043	17.473	24.539	27.908
Comb14	50.575	92.259	52.571	104.207	33.536	17.480	20.990	28.035
Comb15	93.448	144.363	48.235	97.359	31.395	30.346	28.236	22.892
Comb16	41.365	90.621	76.433	139.101	34.050	30.053	17.976	30.924

The AP foundation mat shall be constructed of reinforced concrete (Reference 2.2.7, Section 4.2.12.1.1) and shall be designed in accordance with ACI 349-01 (Reference 2.2.8) per the PDC (Reference 2.2.7, Section 4.2.11.4.1).

Material properties used in SAP2000 (Reference 2.2.11) model:

Concrete: Concrete Compressive strength = 5000 psi (Reference 2.2.7, Section 4.2.11.6.2)
Modulus of Elasticity, $E_s = 617303\ k/ft^2$ for 5000 psi concrete (Reference 2.2.7, Section 4.2.11.6.6) using formula $Ec = Wc^{1.5}\ 33\ (f'c)^{1/2}$
Where Wc is the unit weight for concrete in lb/ft^3.
Poisson's Ratio, $\nu = 0.17$ (Reference 2.2.7, Section 4.2.11.6.6)
Weight of concrete = 150 pcf (Reference 2.2.7, Section 4.2.11.6.6)

Reinforcing steel shall comply with ASTM A706, grade 60 (Reference 2.2.7, Section 4.2.11.6.2).

Use same effective depth (d) for top and bottom reinforcing for ease of calculation.

Calculate Moment and Shear Capacity of 3 ft Thick Foundation Mat

Depth of foundation mat = 3 ft = 36”

Determine the effective structural depth “d” by using one layer of number 11 rebar at 8in. on-center each-way at top and bottom of mat:

For following notations, see ACI 349-01 (Reference 2.2.8, Sections 7 thru 11).

$$d = 36"-3"(\text{cover}) - 1.5d_b = 36"-3"-1.5(1.41") = 30.9"$$

(For cover, see Reference 2.2.8, Section 7.7.1(a))

Minimum reinforcement in each direction each face per foot width of flexural member:

ρ_{min} = 0.0012 Minimum ratio per, ACI 349-01 (Reference 2.2.8, Section 7.12.2)
As, min = 0.0012*12*30.9 = 0.44 in^2 / ft
ρ_{min} = 0.0018 Minimum ratio per Section 7.12.5, ACI 349-01 (Reference 2.2.8)
As, min = 0.0018*12*30.9 = 0.67 in^2 / ft

Per ACI 349-01 (Reference 2.2.8), Section 10.5.1, eq. 10-3,

As, min = $3\sqrt{f_c^{'}}\ bwd\,/\,fy$ = 3*√5000*12*30.9/60,000 = 1.31 in^2 **governs**

Try number 11 rebar at 8 in. on-center, each way, each face, A_s, provided = 2.34 in^2 > 1.31 in^2
Calculate the moment capacity for one layer of number 11 rebar at 8 in. on-center, A_s = 2.34 in^2:

$$\phi M_n = \phi A_s f_y (d - \frac{a}{2}) \geq M_u \qquad \text{(Reference 2.2.10, Eq. 8-2)}$$

ϕ = Strength reduction factor for flexure=0.9 (Ref. 2.2.8, Section 9.3.2.2(a))

where

$$a = \frac{A_s f_y}{0.85 f_c^{'} b} = \frac{2.34\ in^2 (60\ ksi)}{0.85\ (5\ ksi)(12")} = 2.75\ in \quad \text{(Reference 2.2.10, Eq. 8-1)}$$

$$\phi M_n = \frac{0.9\ (2.34\ in^2)(60\ ksi)(30.9"-\frac{2.75"}{2})}{12\ in/ft} = 310.9\ ft-k/ft$$

Determine the shear capacity of concrete requirement per ACI 349-01 (Reference 2.2.8, Chapter 11)

$$\phi V_c = \phi 2\sqrt{f_c^{'}}\ bd = \frac{0.85\ (2)\sqrt{5000\,psi}\ (12\ in/ft)(30.9in)}{1000\,lb/kip} = 44.57\ k/ft \quad \text{(Reference 2.2.8,}$$

Eq. 11-3)

ϕ = strength reduction factor for shear = 0.85 (Reference 2.2.8, Section 9.3.2.3)

Moment and shear capacity was compared to demand from the contour plots for M11, M22, V13 and V23. The torsional moment M12 was added to demand values for M11 and M22 to determine demand. The following tables 6.6.2 and 6.6.3 summarize the maximum demand for moments and shears in comparison to the capacity.

Table 6.6.2 Maximum Moment D/C Ratios for 3 ft thick Mat (per foot width)

Maximum Moment M (k-ft)[a]	Maximum Moment M12 (k-ft)[a]	Total Demand (D) (k-ft) M_{ud}=M+M12	Capacity (C) (k-ft) = ϕM_n	D/C Ratio	Load Combination	Minimum and Maximum Moment [a]
−M11 −93.5	−31.4	124.9	310.9	0.40	15	pp. 116 and 118
+M11 144.4	+30.4	174.8	310.9	0.56	15	pp. 116 and 118
−M22 −76.4	−34.1	110.5	310.9	0.36	16	pp. 122 and 123
+M22 139.1	+30.1	169.2	310.9	0.54	16	pp. 122 and 123

[a] For maximum moment, see Table 6.6.1 and Attachment C.
C = capacity; D = demand.

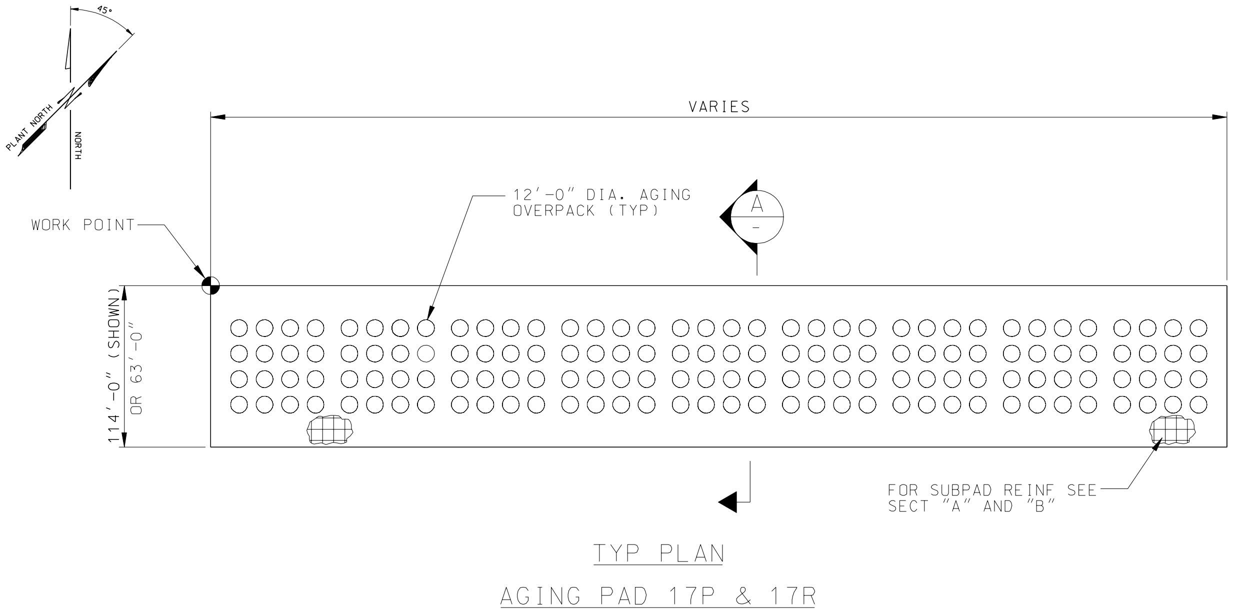
Table 6.6.3 Maximum Shear D/C Ratios for 3 ft thick Mat (per foot width)

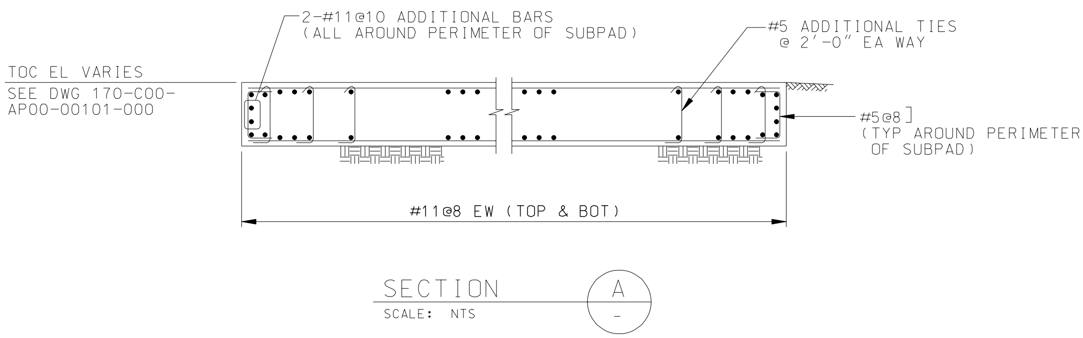
Maximum Shear Vu (kips)[a]	Capacity (C)= ϕ *Vc* (kips)	D/C	Load Combination	Maximum Shear[a]
V13 30.3	44.57	0.68	9	p. 89
V23 30.9	44.57	0.69	16	p. 125

[a] Table 6.6.1 and Attachment C
C = capacity; D = demand

Although shear reinforcing is not required, conservatively provide nominal vertical ties, #5 bars at 24 in. centers each way to allow for impact load during seismic event for concentrated loads such as Aging Overpacks and Transporter.

For a foundation plan view and section showing flexural and shear reinforcement, see Figure 6.6.1.





NOTES:

1. MININUM CONCRETE COMPRESSIVE STRENGTH SHALL BE 5000 PSI.
2. REINFORCEMENT SHALL BE ASTM A706, GRADE 60.
3. CONCRETE AND REINFORCING SHALL BE DETAILED AND INSTALLED PER ACI 349-01.

Figure 6.6.1 Foundation Mat Plan and Cross Section

The foundation mat at south end of Aging Pad 17R (Reference 2.2.3) provides storage for Horizontal Aging Module (HAM). This module shall be installed side by side in one (1) row of fifty (50) on each pad. This grouping shall include a shield wall at each end and on the back (Reference 2.2.3). The drawing for HAM (Reference 2.2.19) shows conceptual configuration and reference dimensions. The drawing for horizontal STC (Reference 2.2.22) and cask tractor (Reference 2.2.23) shows estimated curb weight of 35 tons, payload of 125 tons and estimated loaded weight of 160 tons. The Payload of 125 tons is less than 200 tons for Aging Overpack and loaded weight of 160 tons for the horizontal transfer trailer is less than that for loaded Site Transporter, both used for foundation design. Section 6.7 provides qualification of pads for the HAMs.

6.7 QUALIFICATION OF PADS FOR THE HORIZONTAL AGING MODULES

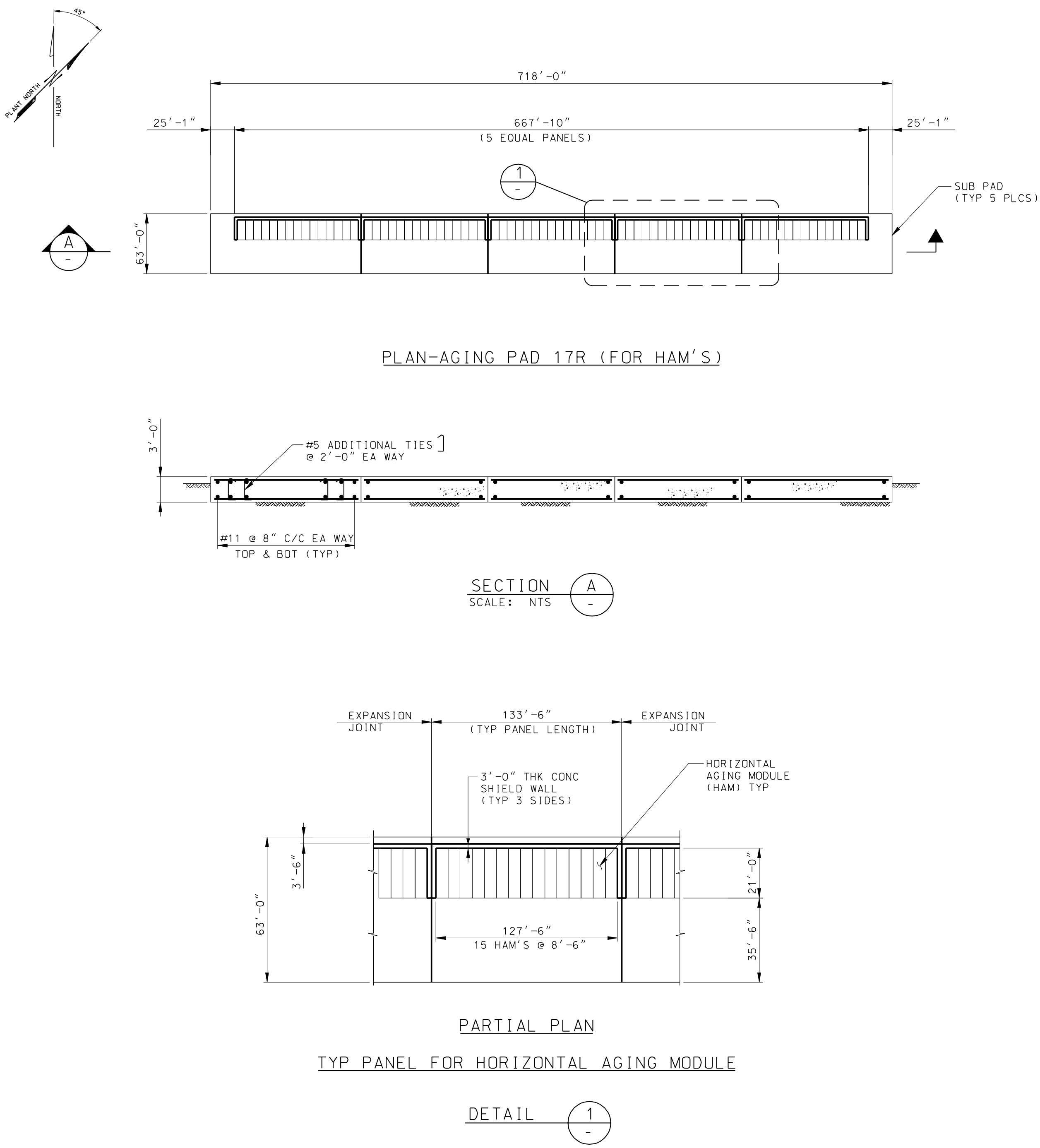
The *Aging Facility General Arrangement Aging Pad 17R Plan* (Reference 2.2.3), indicates that in addition to the aging pad for the Vertical DPC Aging Overpack Casks, at least two pads will be provided for the Horizontal Aging Modules (HAMs). Even though the analysis documented in this calculation was performed for the vertical aging overpack casks foundation pads, the analysis also applies to the pads for the HAMs. These pads will also be 3'-0" thick and reinforced in the same way as the pads for the vertical aging casks.

The HAMs, including the 3'-0" radiation shield wall at the back ends are about 24'-0" long by 8'-6" wide and weigh 646.5 kips (Assumption 3.1.3). Thus they place a pressure of about 4.24 ksf (Section 6.3-D) on the pad surface. The Vertical DPC Aging Overpack Casks weigh about 250 tons and have a footprint, ignoring the lift slots, of about 12'-0" diameter (Reference 2.2.17). This yields a distributed load of 4.11 ksf, which is close to that for the HAMs. The vertical casks thus place a similar pressure on the pad surface and will envelope the modeling of the HAMs loads.

The other major feature that the current analytical model should address to permit it to envelope the pads for the HAMS is the unsymmetrical layout of the HAMs on the pads. The latest layout of the HAM pads (ref. 2.2.3) indicates that the HAMs are offset on the pads such that the back edge of the shield wall for the HAMs is located a few feet from the edge of the pad. This feature is adequately modeled in the current analysis by having the pads for the vertical overpack casks cut off only a few feet from the edge of the casks at the West end of the model.

The current analytical model for aging overpacks sufficiently envelopes the major feature and models the key differences between the two pads (aging overpacks and HAMs) such that it can serve as the design model for both pads.

Figure 6.7.1 shows the HAM Foundation Plan, Section and Details.



NOTES:

1. MININUM CONCRETE COMPRESSIVE STRENGTH SHALL BE 5000 PSI.
2. REINFORCEMENT SHALL BE ASTM A706, GRADE 60.
3. CONCRETE AND REINFORCING SHALL BE DETAILED AND INSTALLED PER ACI 349-01.

Figure 6.7.1 HAM Foundation Plan, Section and Details.

7. RESULTS AND CONCLUSIONS

7.1 RESULTS

The primary results of this calculation are summarized below:

- Design forces and moments:

  The contour plots shown in Attachment C represent the shear forces and bending moments that will occur in the AP Foundation Mat under the design loading combinations. The minimum and maximum values shown on the contours and listed in Table 6.6.1 were used to obtain the design forces for designing the flexural and shear reinforcement for the AP Foundation Mat.

- Foundation Mat flexural reinforcement:

  The 3 ft thick Foundation Mat was designed for a maximum bending moment, $M_{u,}$ of 174.8 k/ft. The reinforcement selected was #11 bars at 8 inch spacing on center, each way, top and bottom. This reinforcement yields a design moment capacity, ϕM_n, of 310.9 ft-k/ft. Therefore, the flexural demand/capacity ratio = M_u / ϕM_n = 0.56 < 1.0.

- Foundation Mat shear reinforcement:

  The 3 ft Foundation Mat was designed for a maximum shear, V_u, of 30.9 k/ft. This is within the concrete capacity, ϕV_c, of 44.57 k/ft, which indicates that no shear reinforcement is required in the mat. The demand/capacity ratio = $A_{v\ required}$ / $A_{v\ provided}$ = 0.69 < 1.0. Provide nominal vertical ties, #5 bars at 24 in. centers each way for Aging Overpacks and HAMs Foundation.

Maximum (ultimate) soil bearing pressure under the foundation mat is 4.11 kips per square foot which is less than (ultimate) allowable capacity of 50 kips per square foot and maximum deformation of link element is 0.319 inch (see Section 6.5.2), which is acceptable.

7.2 CONCLUSIONS

The outputs are reasonable compared with the inputs, and the results are suitable for the intended use. The maximum shear forces and moments occur at the corner areas of the structure, as expected, due to non-orthogonal effects. The flexural and shear reinforcement are indicative of the Foundation Mat thickness and provides a reasonable design.

The current analytical model for aging overpacks sufficiently envelopes the major feature and models the key differences between the two pads (aging overpacks and HAMs) such that it can serve as the design model for both pads.

ATTACHMENT A
SAP2000 INPUT FILE

SAP File (CD 1 of 1)

170-DBC-AP00-00100-000-00A.SDB

ATTACHMENT B
SAP2000 OUTPUT FILES

(CD 1 0f 1)

Load Combination 1.xls

Load Combination 2.xls

Load Combination 3.xls

Load Combination 4.xls

Load Combination 5.xls

Load Combination 6.xls

Load Combination 7.xls

Load Combination 8.xls

Load Combination 9.xls

Load Combination 10.xls

Load Combination 11.xls

Load Combination 12.xls

Load Combination 13.xls

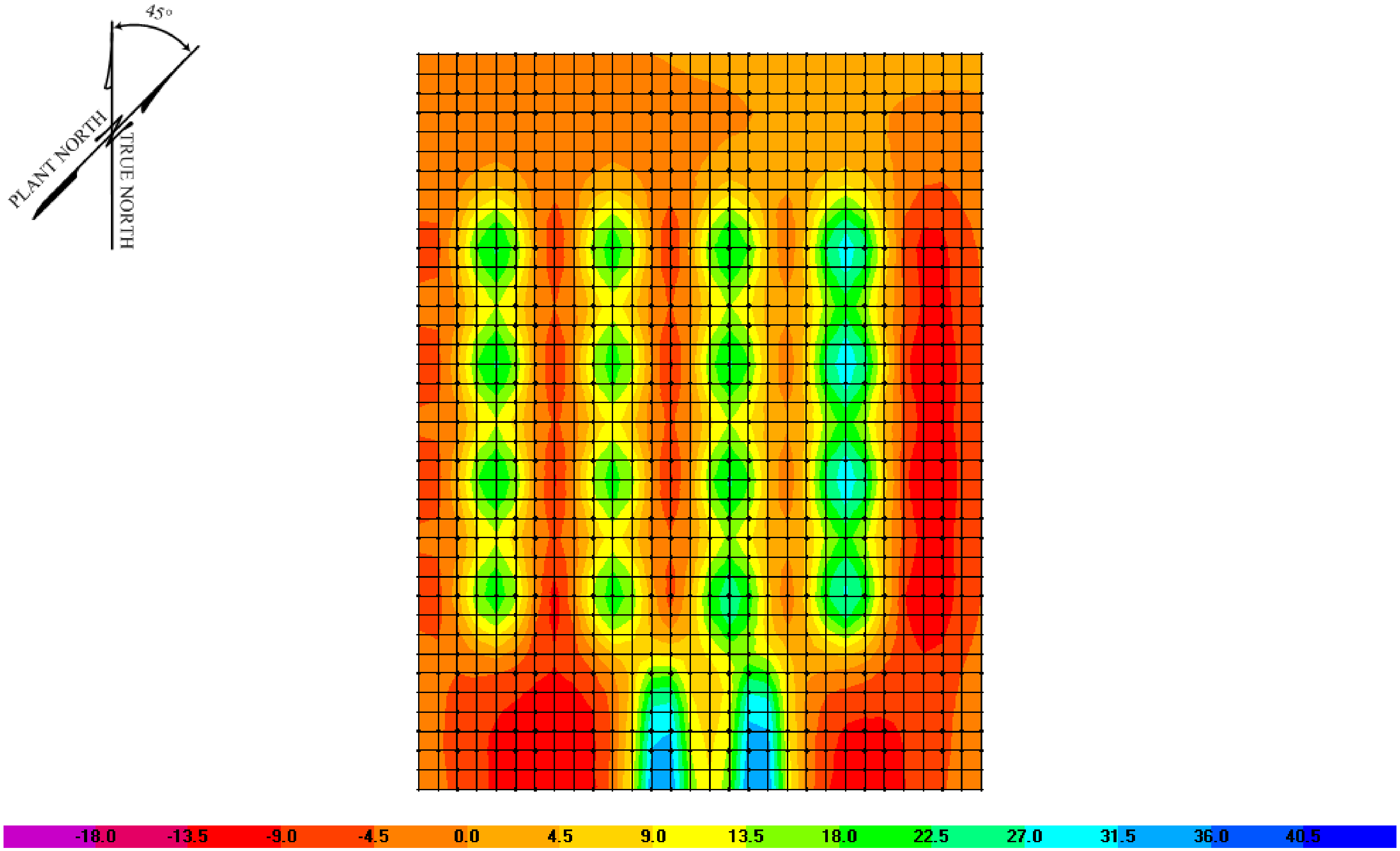
Load Combination 14.xls

Load Combination 15.xls

Load Combination 16.xls

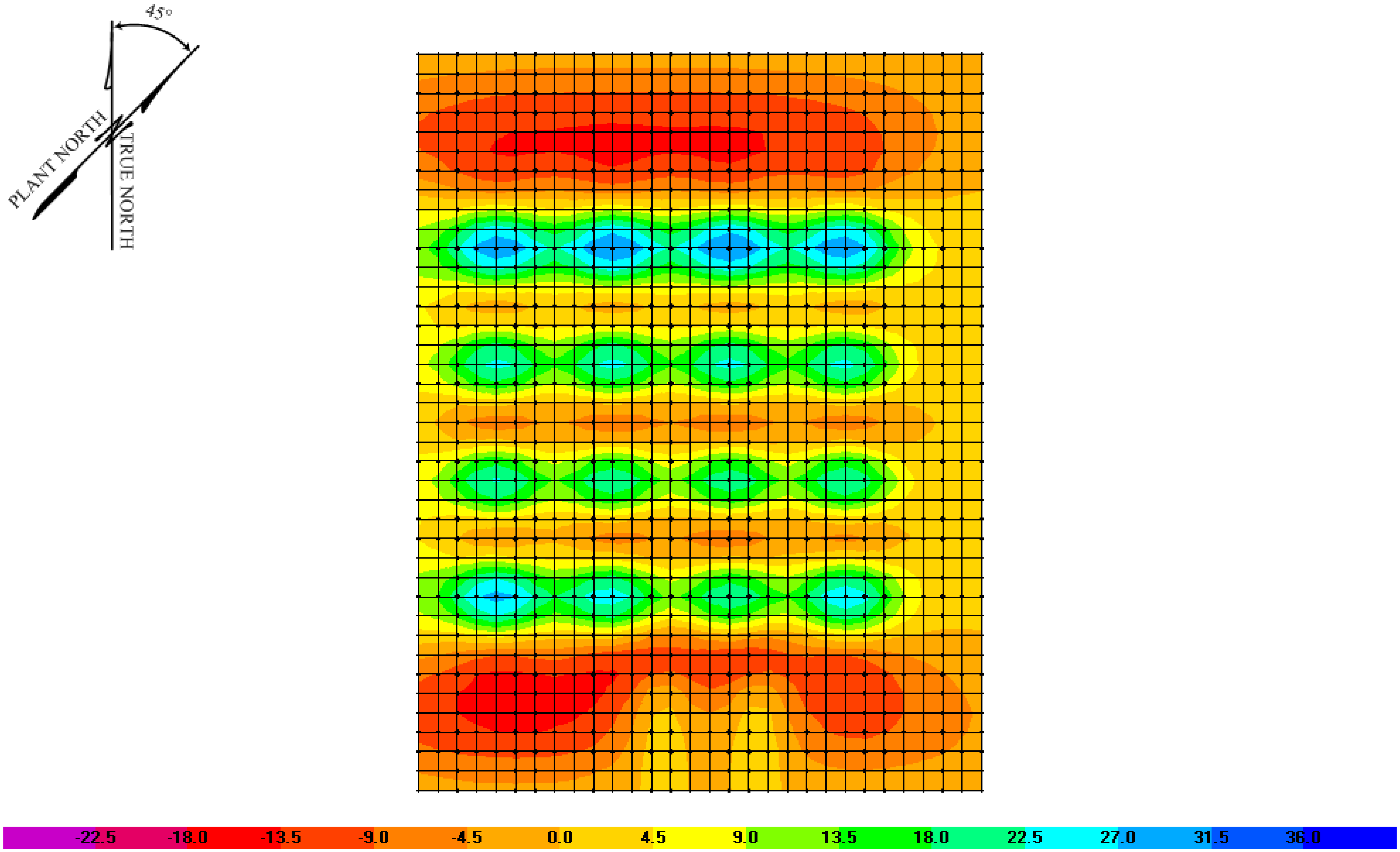
ATTACHMENT C
MOMENT AND SHEAR CONTOUR DIAGRAMS

ATTACHMENT C
MOMENT AND SHEAR CONTOUR DIAGRAMS



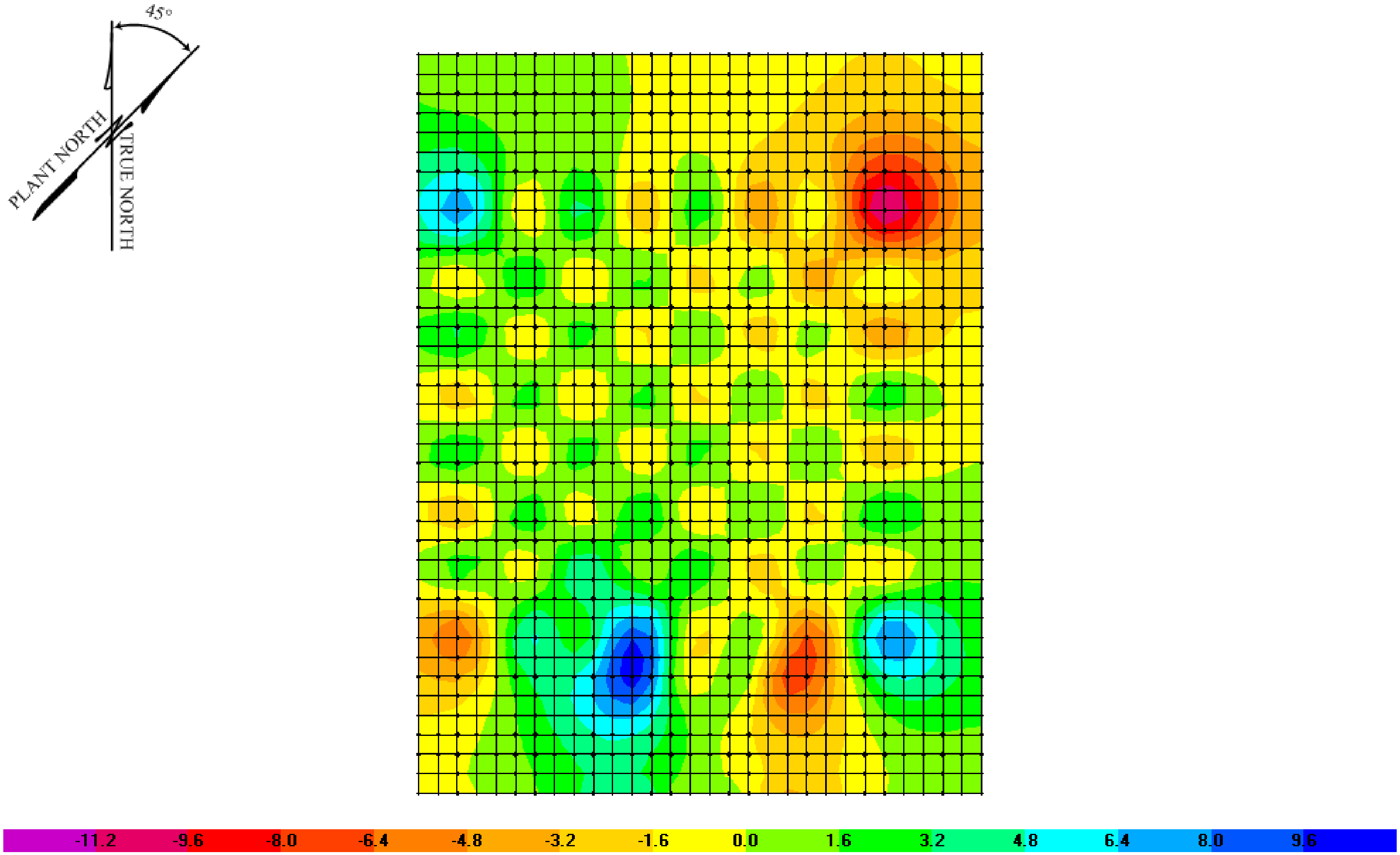
(MIN = -21.531 (k-ft), MAX = 41.613 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 1 (D+L+CASKL+TRANSL_Center)



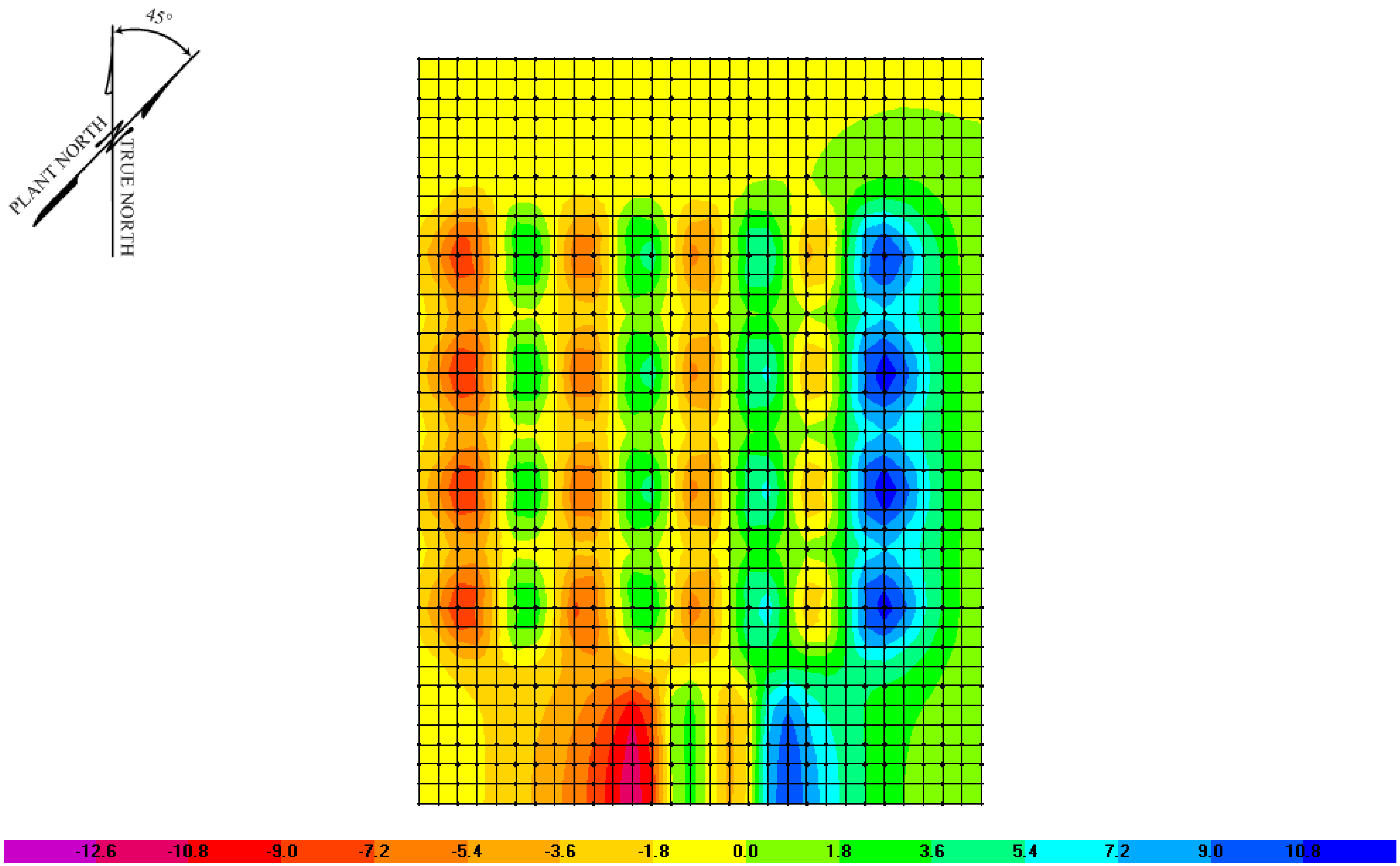
(MIN = -25.312 (k-ft), MAX = 38.254 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 1 (D+L+CASKL+TRANSL_Center)



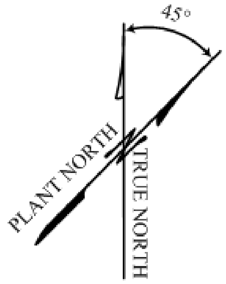
(MIN = -11.329 (k-ft), MAX = 10.999 (k-ft))

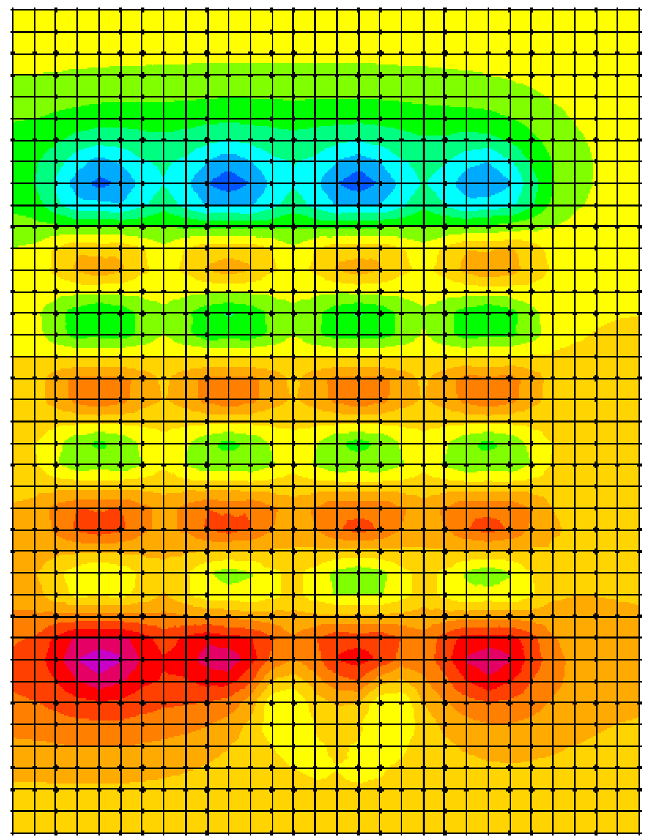
3 ft. Thick Resultant M12 Diagram - Combination 1 (D+L+CASKL+TRANSL_Center)



(MAX = 13.673 (kips))

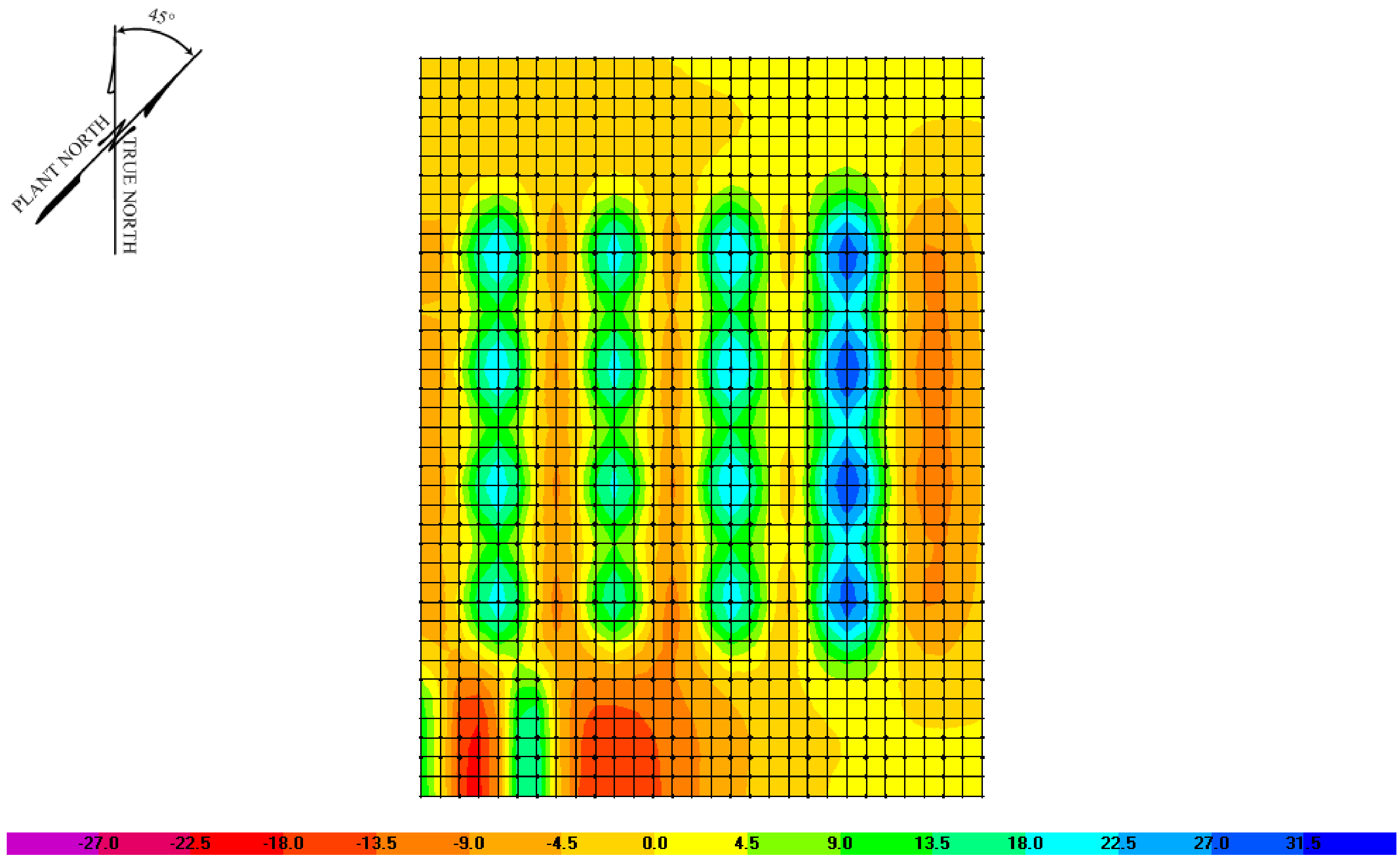
3 ft. Thick Resultant V13 Diagram - Combination 1 (D+L+CASKL+TRANSL_Center)





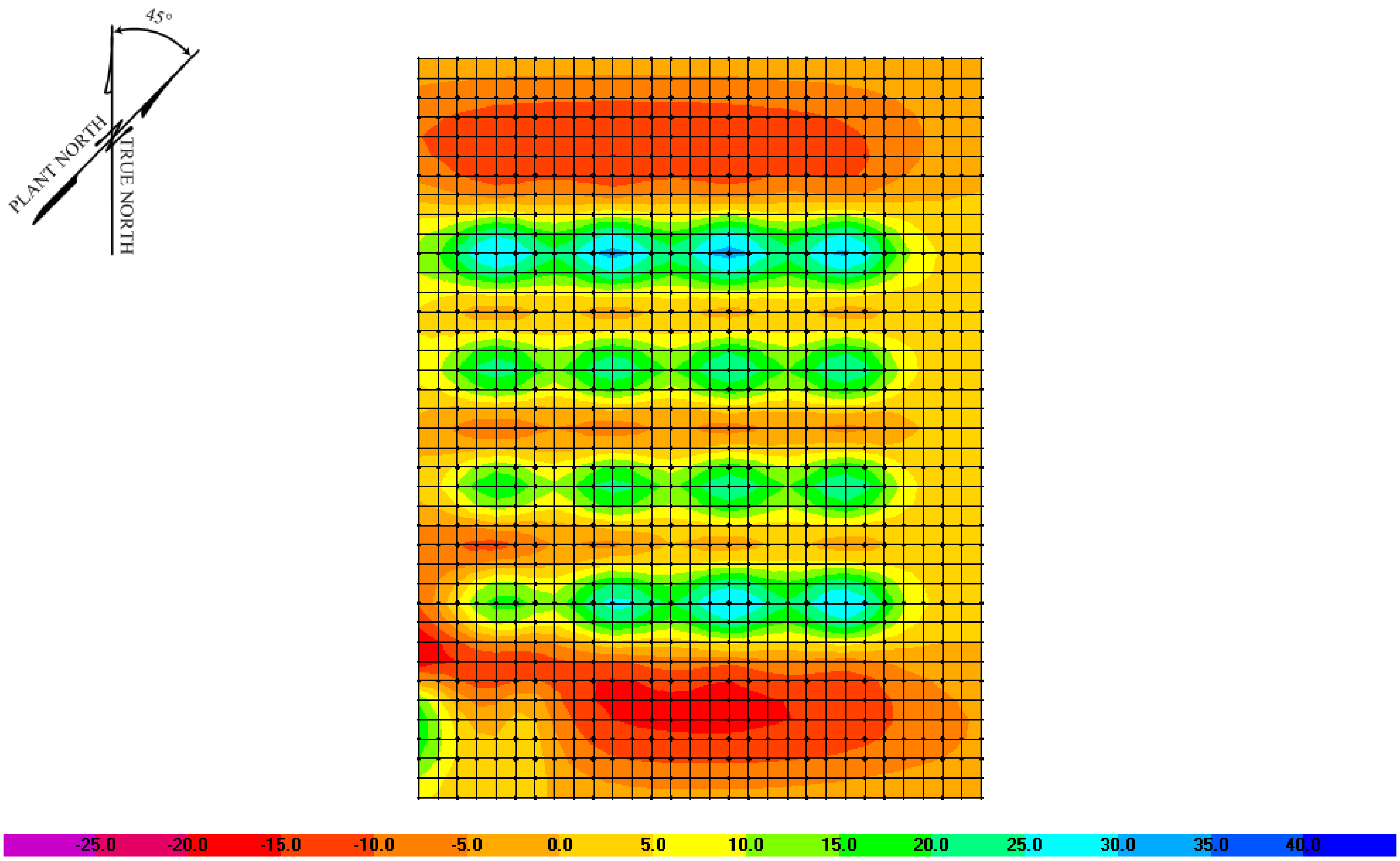
(MAX = 13.704 (kips))

3 ft. Thick Resultant V23 Diagram - Combination 1 (D+L+CASKL+TRANSL_Center)



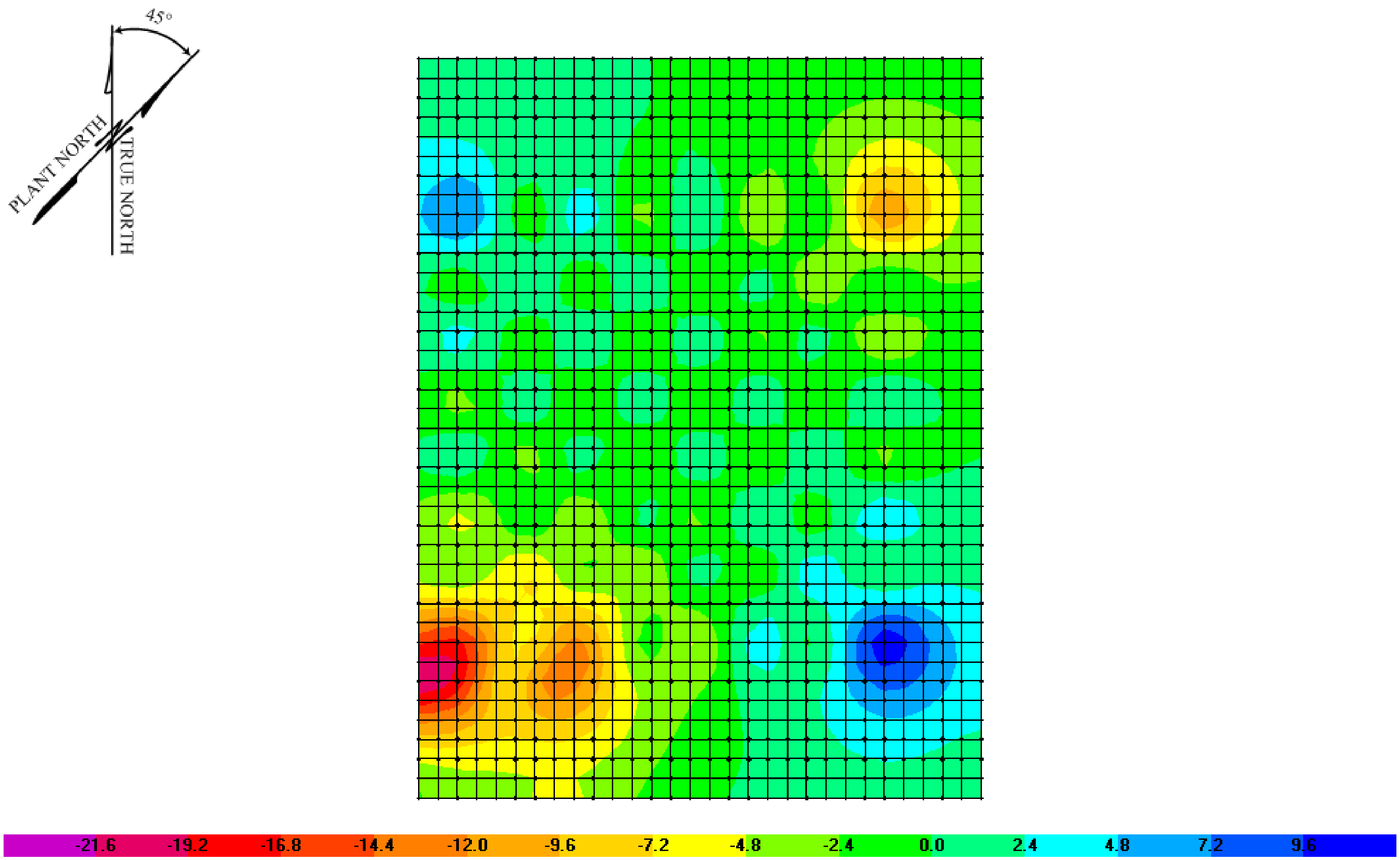
(MIN = -29.644 (k-ft), MAX = 35.556 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 2 (D+L+CASKL+TRANSL_Edge)



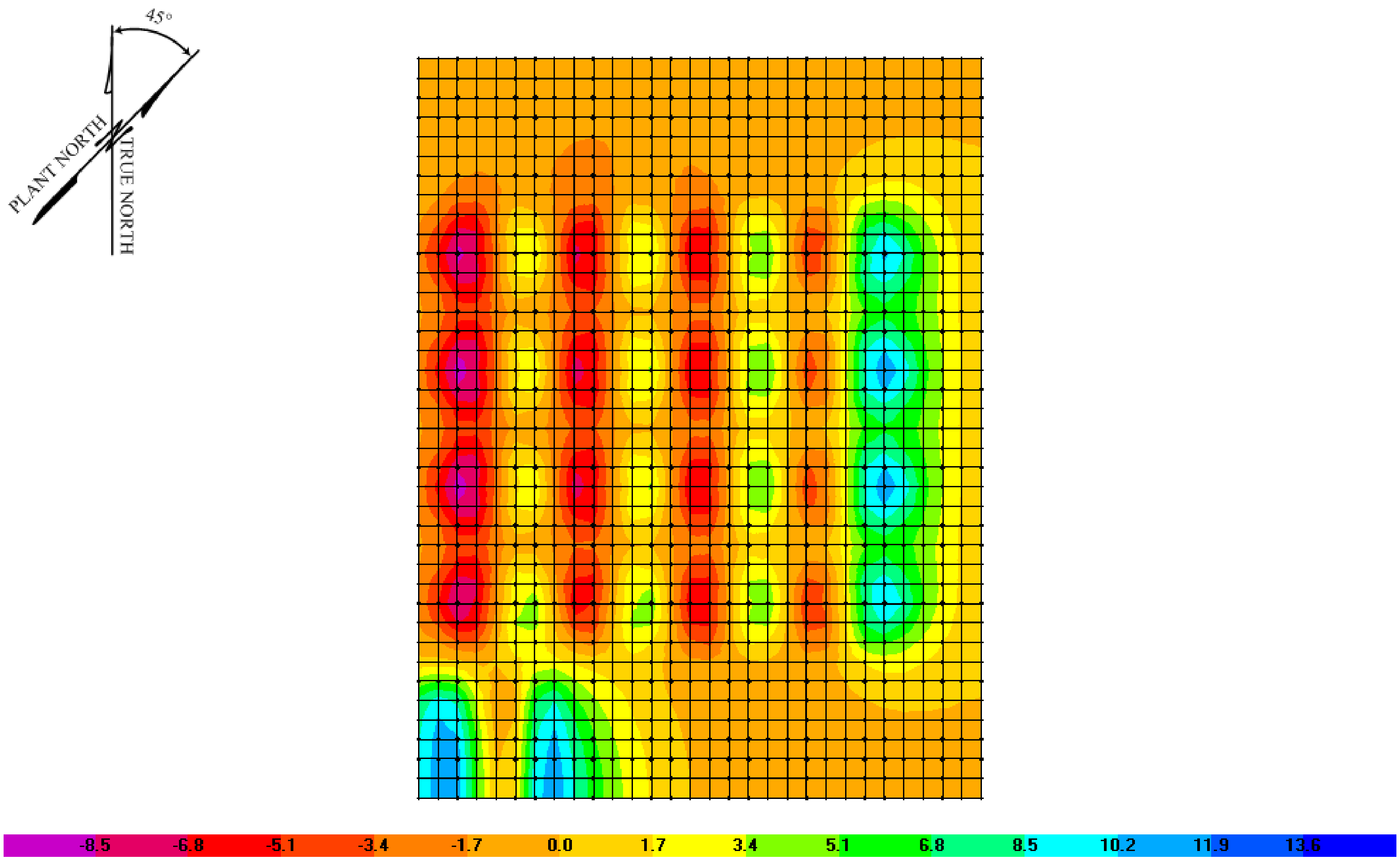
(MIN = -27.052 (k-ft), MAX = 38.647 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 2 (D+L+CASKL+TRANSL_Edge)



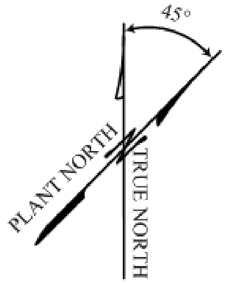
(MIN = -21.728 (k-ft), MAX = 11.099 (k-ft))

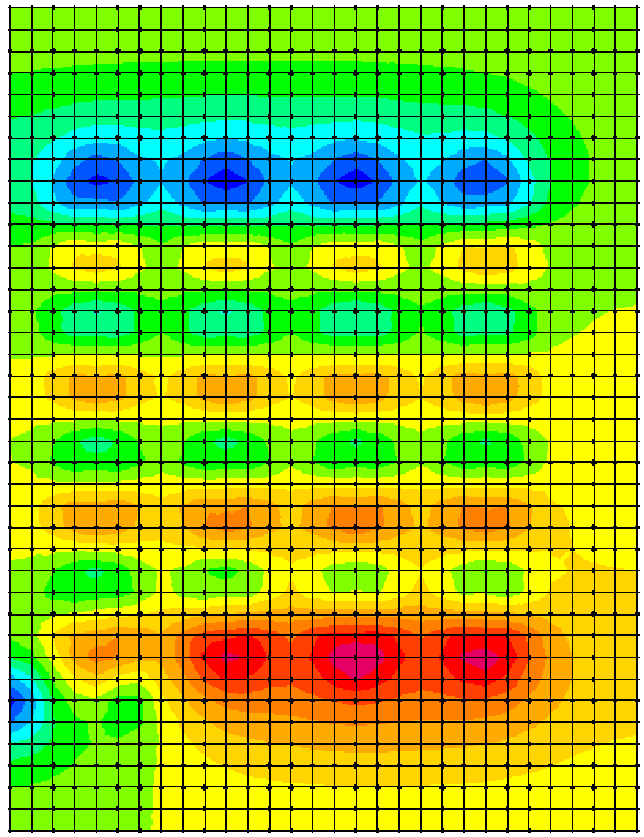
3 ft. Thick Resultant M12 Diagram - Combination 2 (D+L+CASKL+TRANSL_Edge)



(MAX = 13.906 (kips))

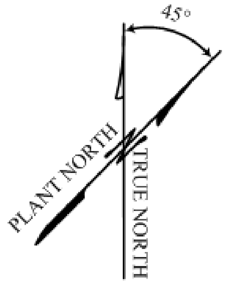
3 ft. Thick Resultant V13 Diagram - Combination 2 (D+L+CASKL+TRANSL_Edge)

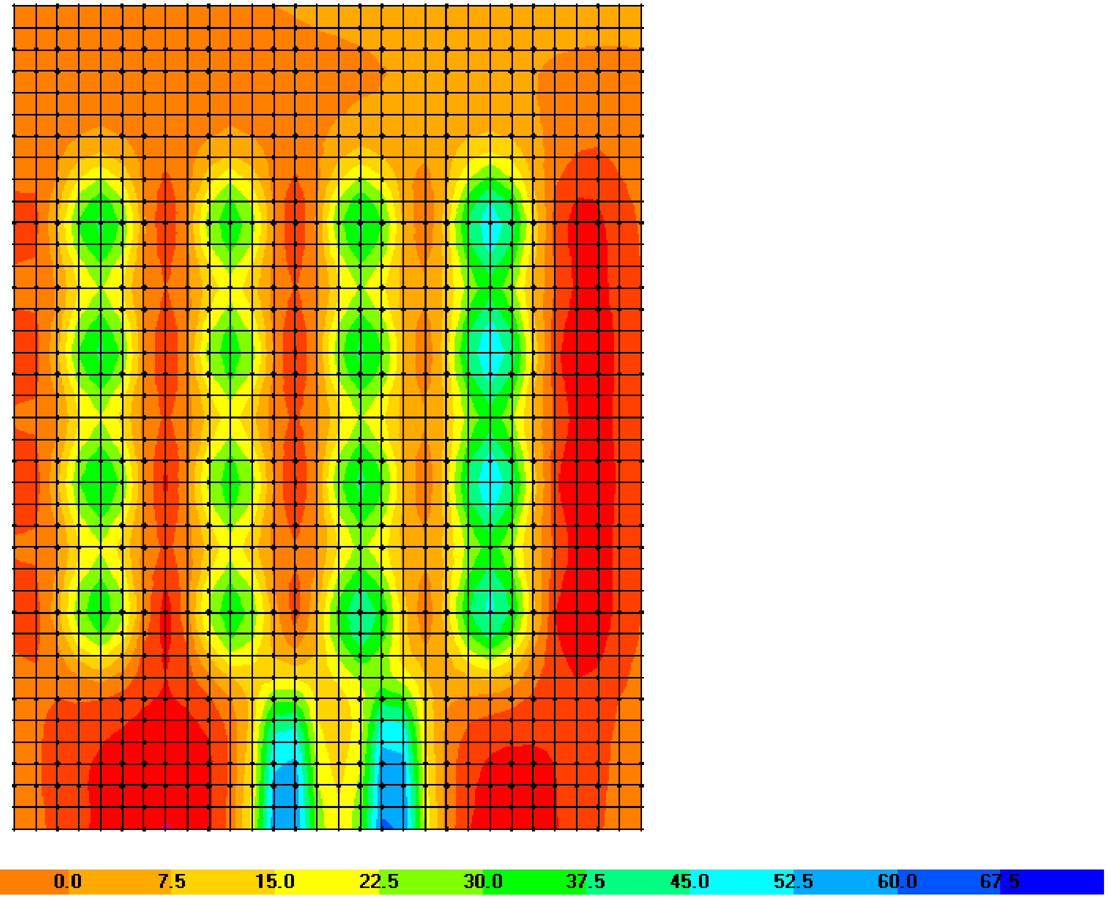




(MAX = 14.447 (kips))

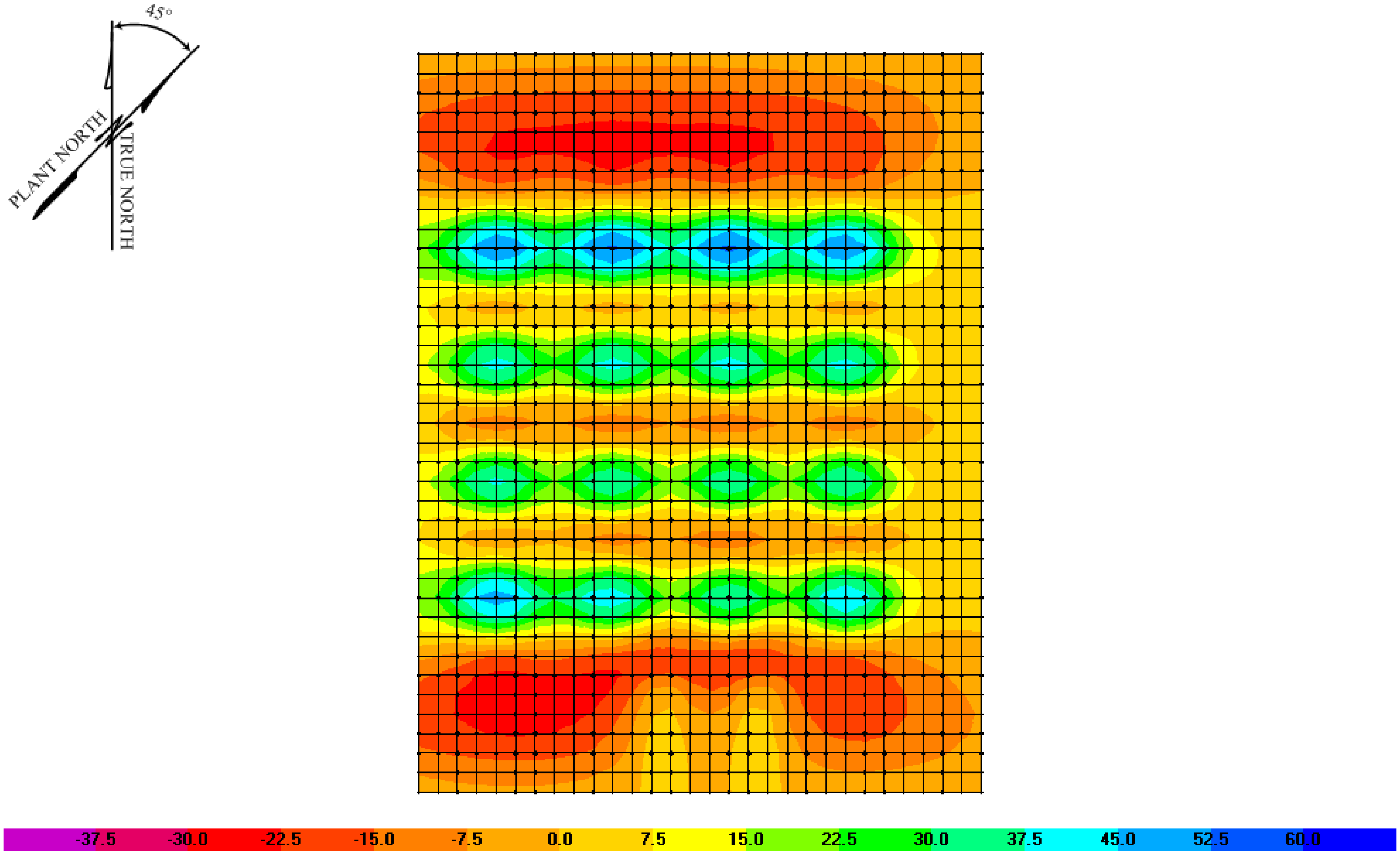
3 ft. Thick Resultant V23 Diagram - Combination 2 (D+L+CASKL+TRANSL_Edge)





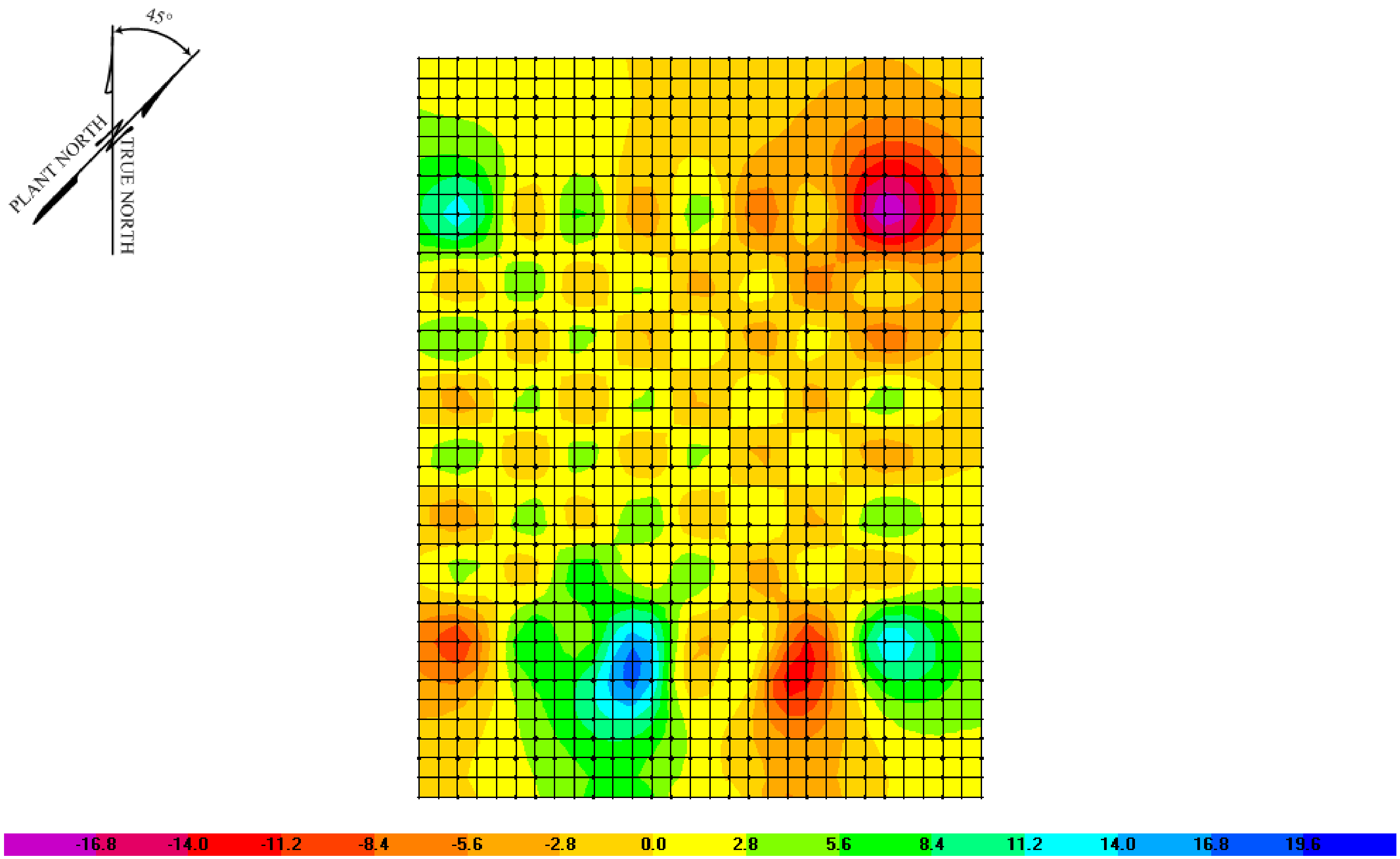
(MIN = -36.603 (k-ft), MAX = 70.742 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 3 (1.4D+ 1.7(L+CASKL+TRANSL_Center))



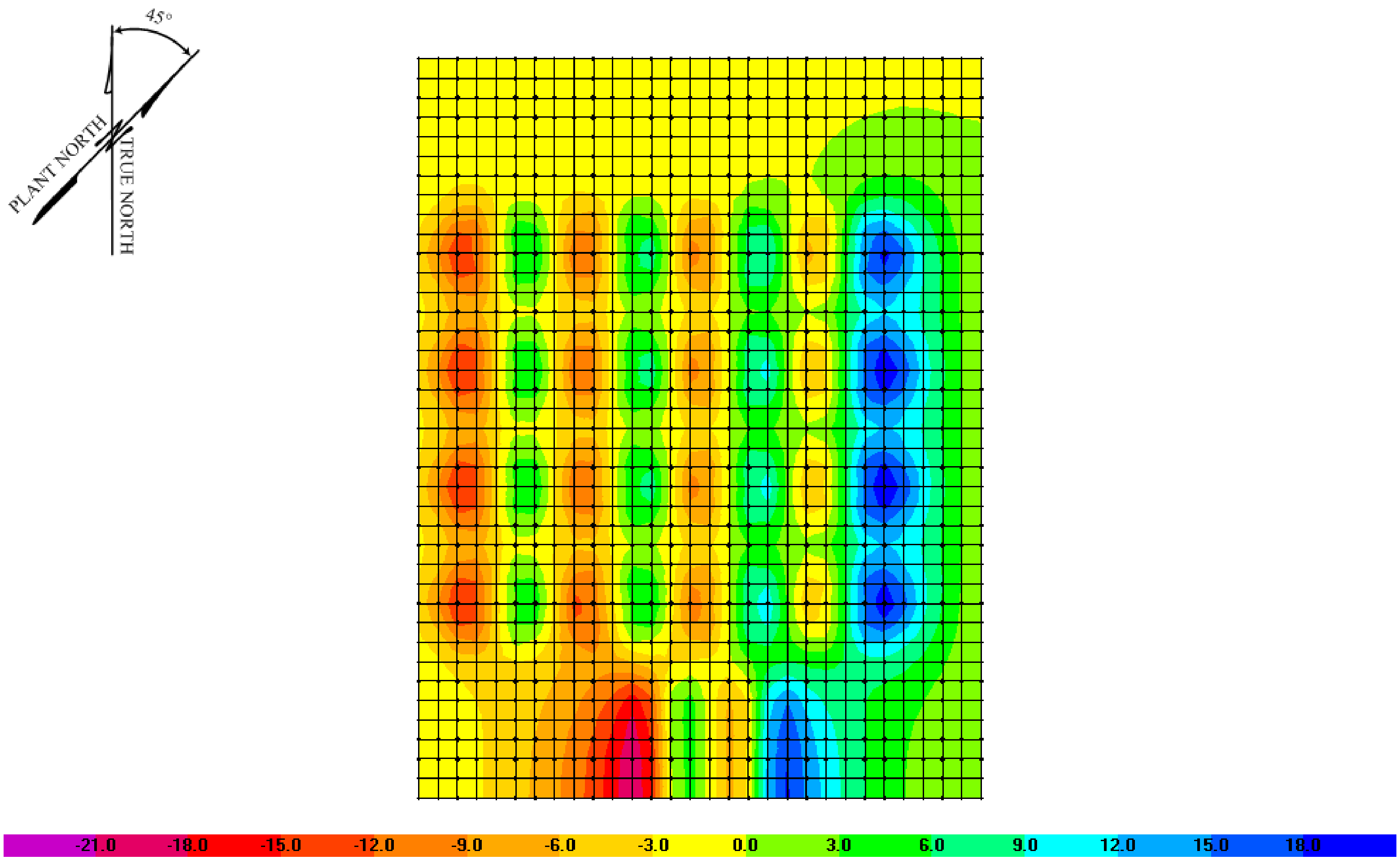
(MIN = -43.031 (k-ft), MAX = 65.032 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 3 (1.4D+ 1.7(L+CASKL+TRANSL_Center))



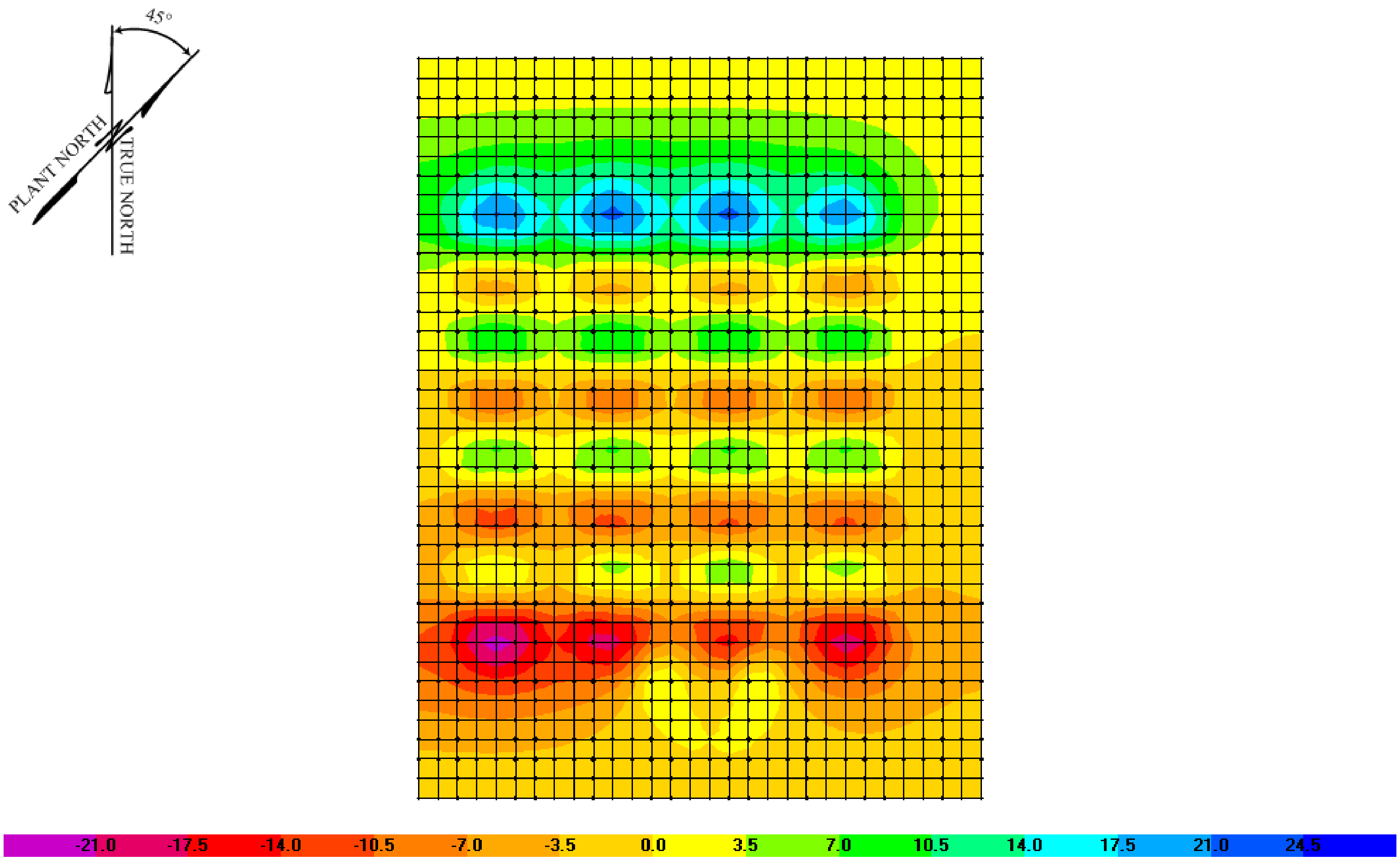
(MIN = -19.260 (k-ft), MAX = 18.698 (k-ft))

3 ft. Thick Resultant M12 Diagram - Combination 3 (1.4D+ 1.7(L+CASKL+TRANSL_Center))



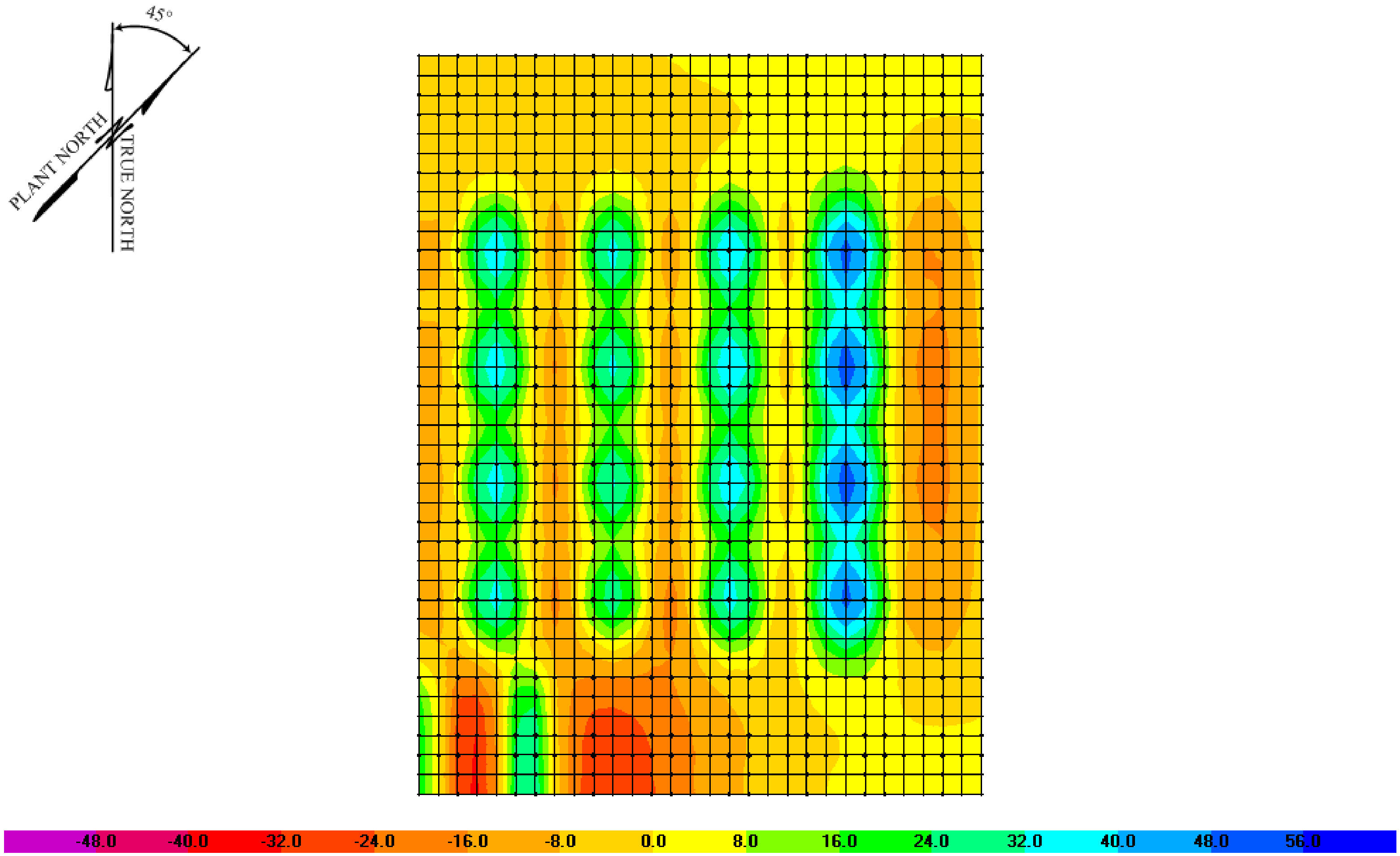
(MAX = 23.244 (kips))

3 ft. Thick Resultant V13 Diagram - Combination 3 (1.4D+ 1.7(L+CASKL+TRANSL_Center))



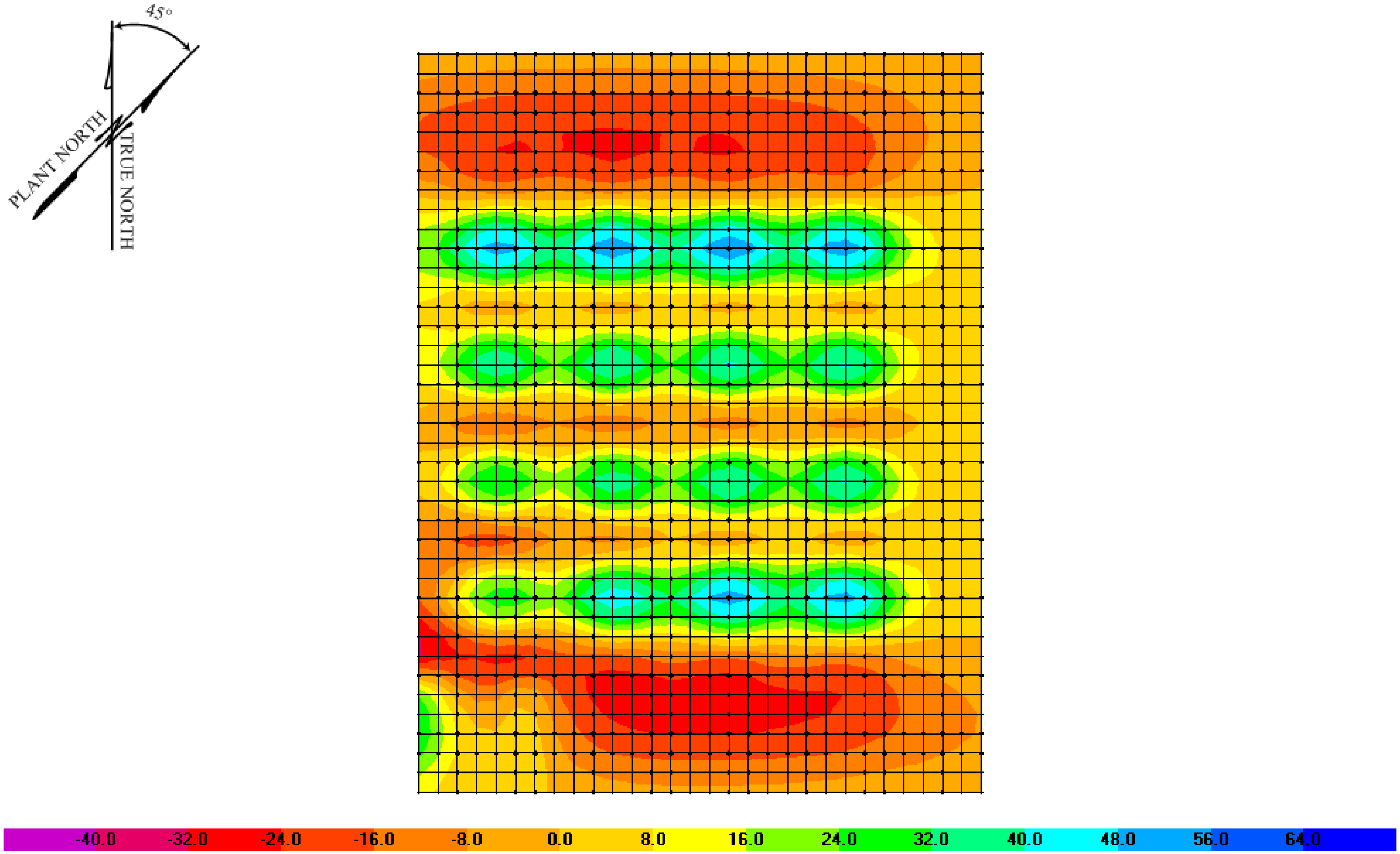
(MAX = 23.297 (kips))

3 ft. Thick Resultant V23 Diagram - Combination 3 (1.4D+ 1.7(L+CASKL+TRANSL_Center))



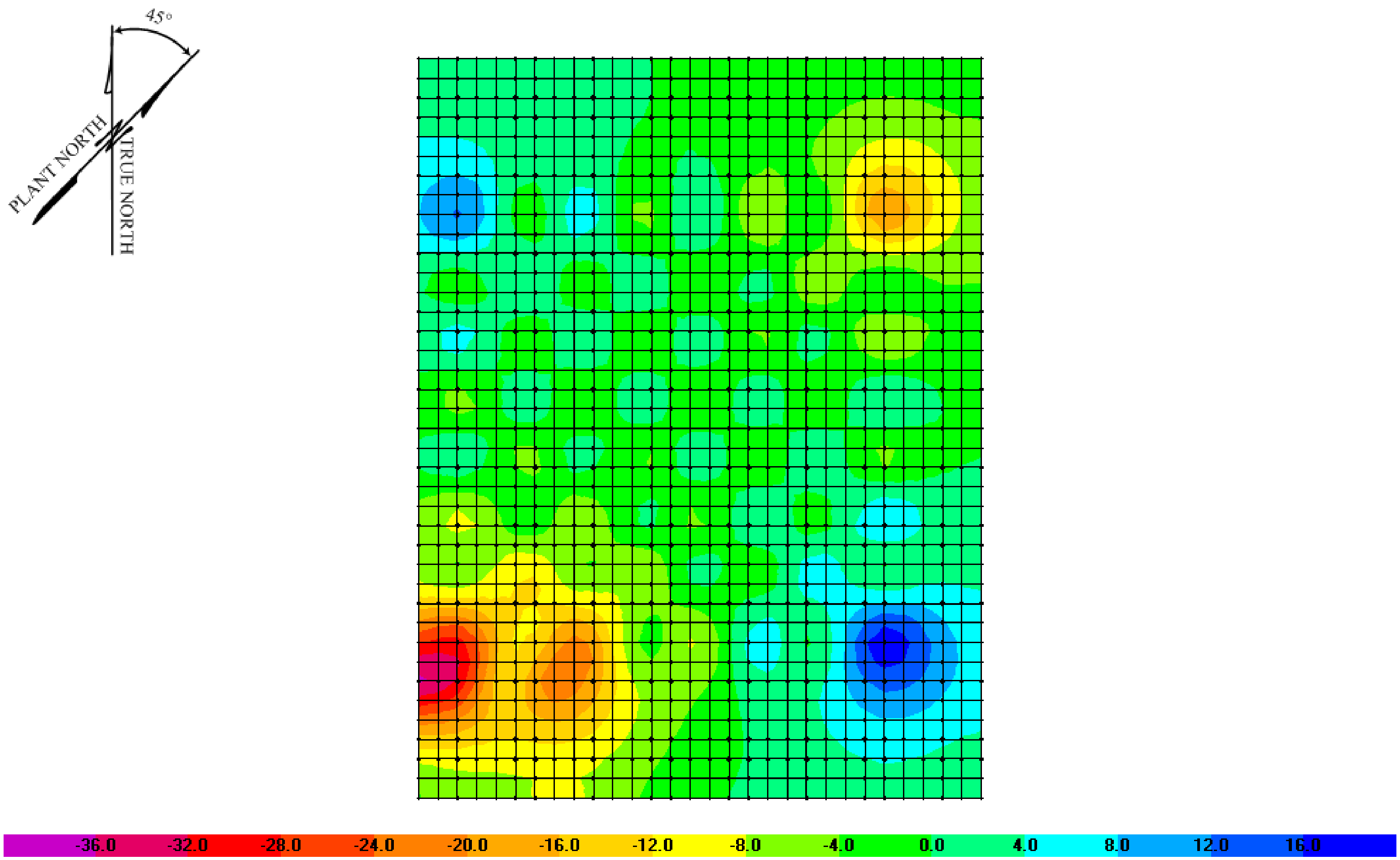
(MIN = -50.396 (k-ft), MAX = 60.446 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 4 (1.4D+ 1.7(L+CASKL+TRANSL_Edge))



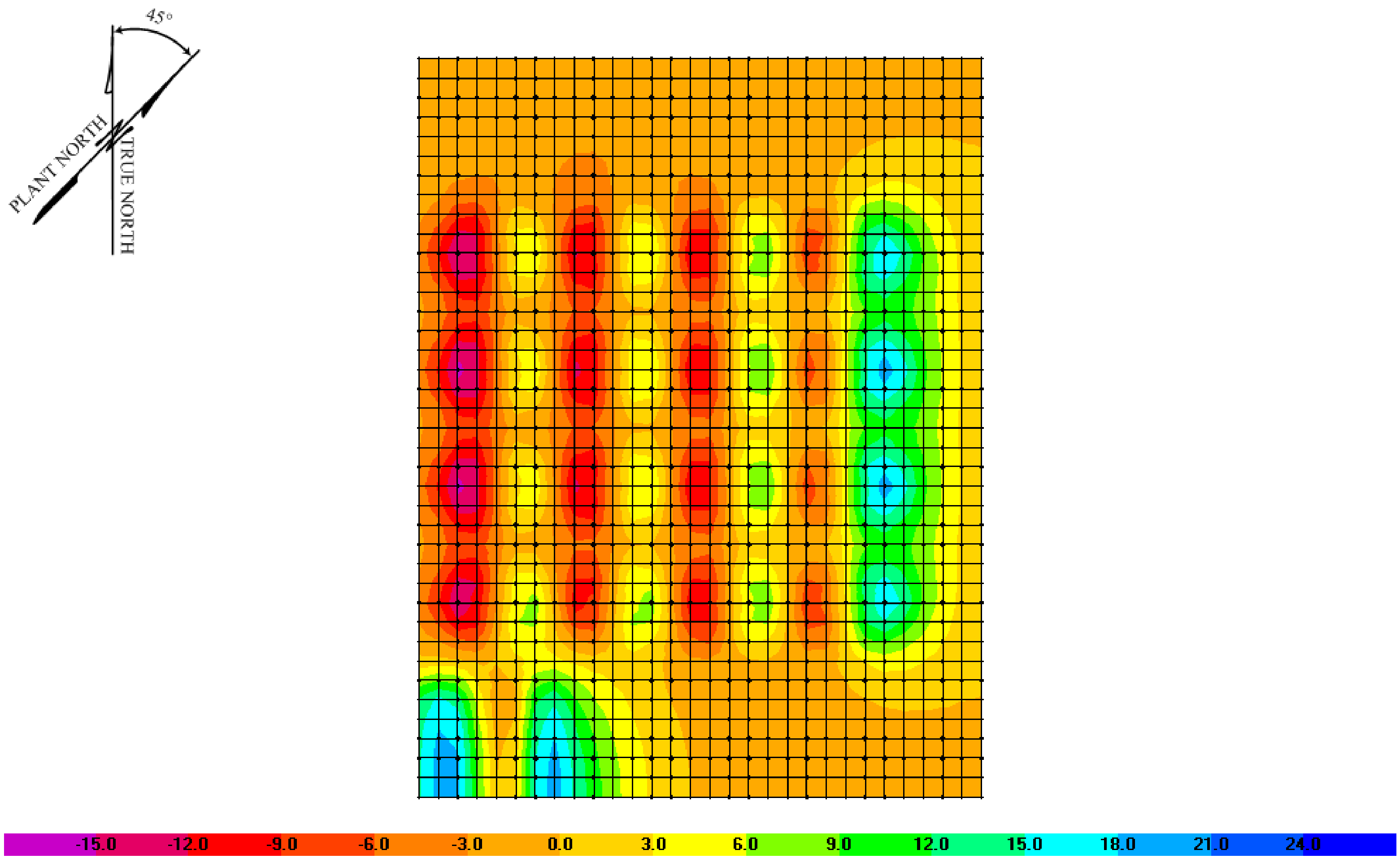
(MIN = -45.989 (k-ft), MAX = 65.700 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 4 (1.4D+ 1.7(L+CASKL+TRANSL_Edge))



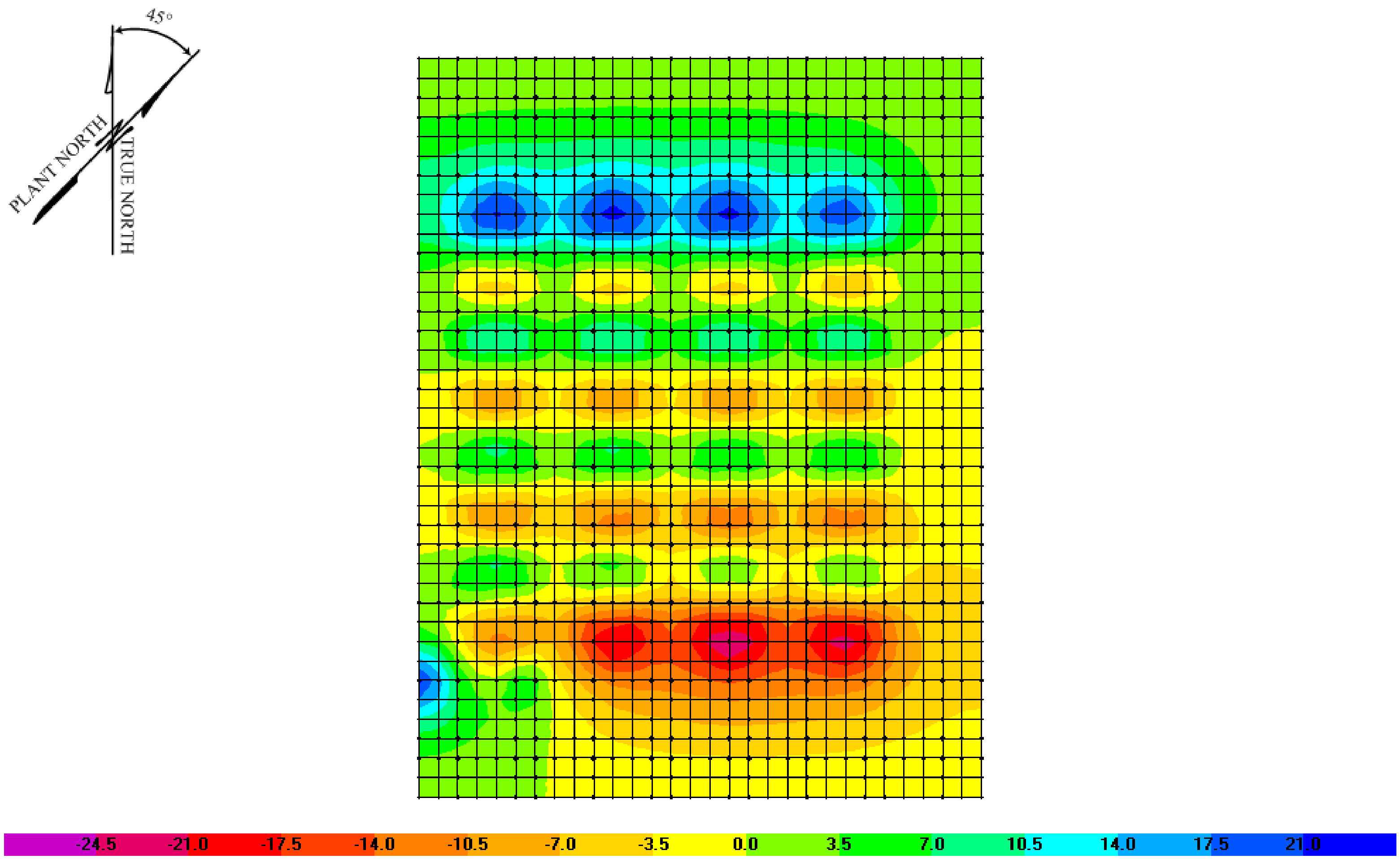
(MIN = -36.938 (k-ft), MAX = 18.868 (k-ft))

3 ft. Thick Resultant M12 Diagram - Combination 4 (1.4D+ 1.7(L+CASKL+TRANSL_Edge))



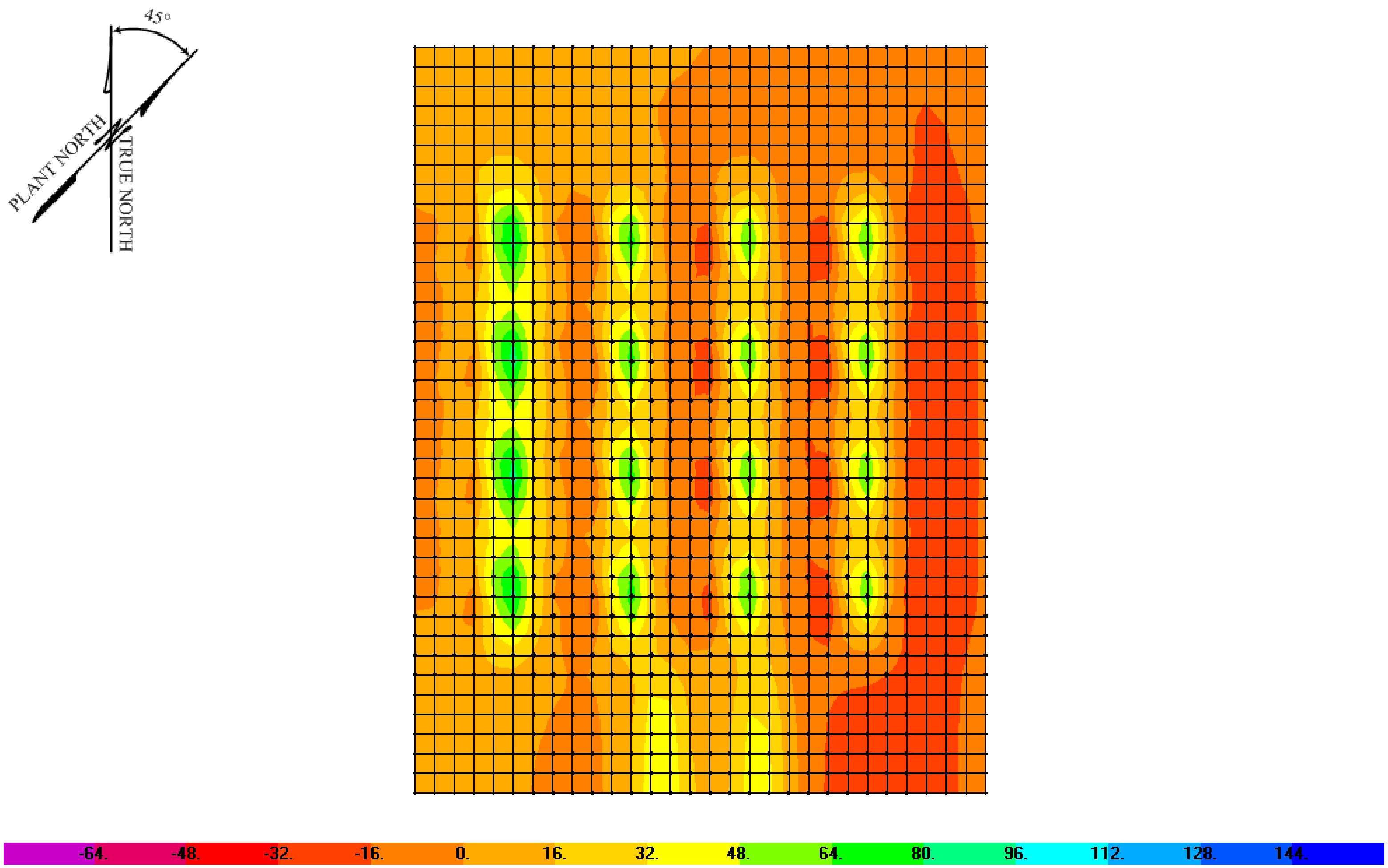
(MAX = 23.640 (kips))

3 ft. Thick Resultant V13 Diagram - Combination 4 (1.4D+ 1.7(L+CASKL+TRANSL_Edge))



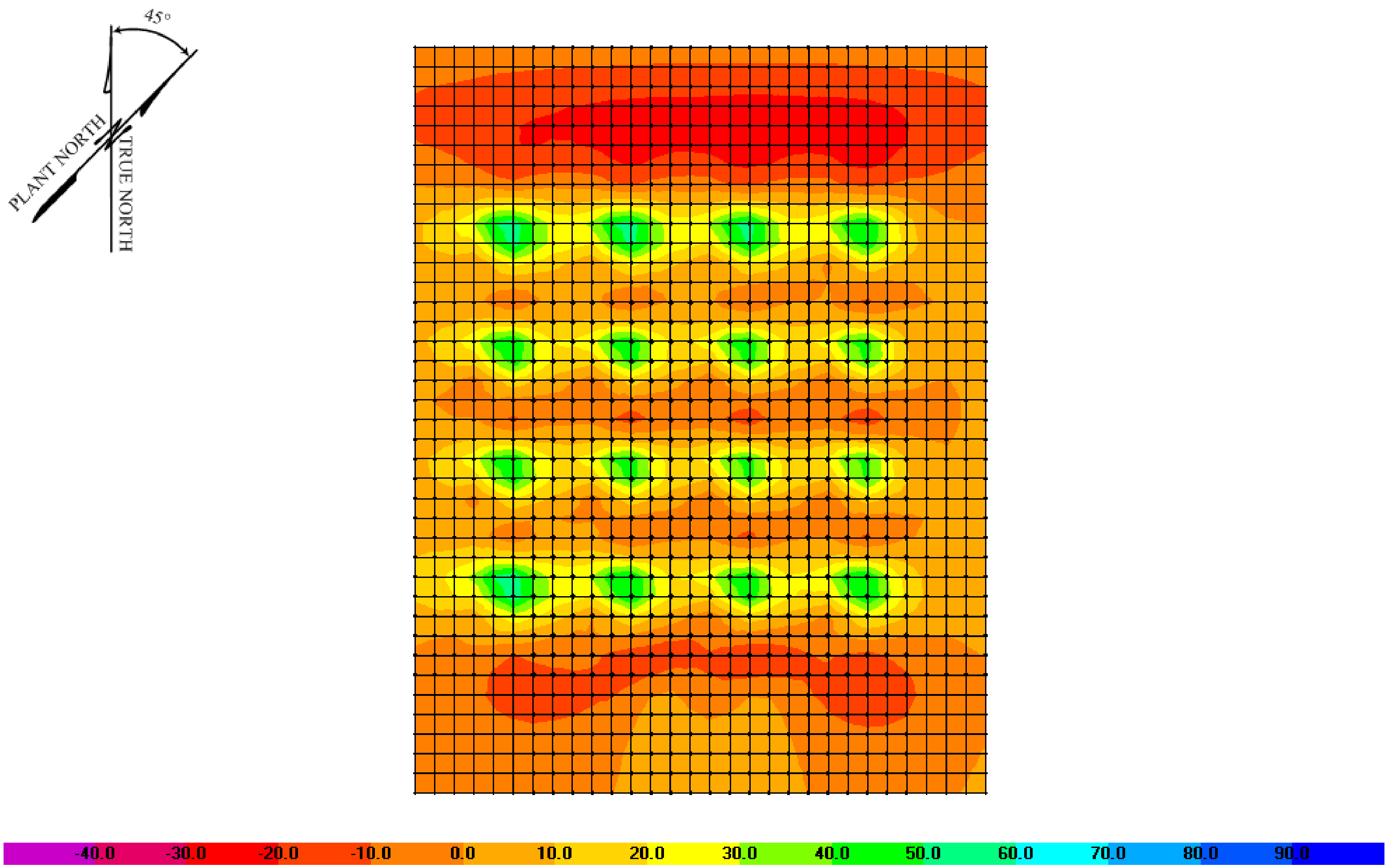
(MAX = 24.560 (kips))

3 ft. Thick Resultant V23 Diagram - Combination 4 (1.4D+ 1.7(L+CASKL+TRANSL_Edge))



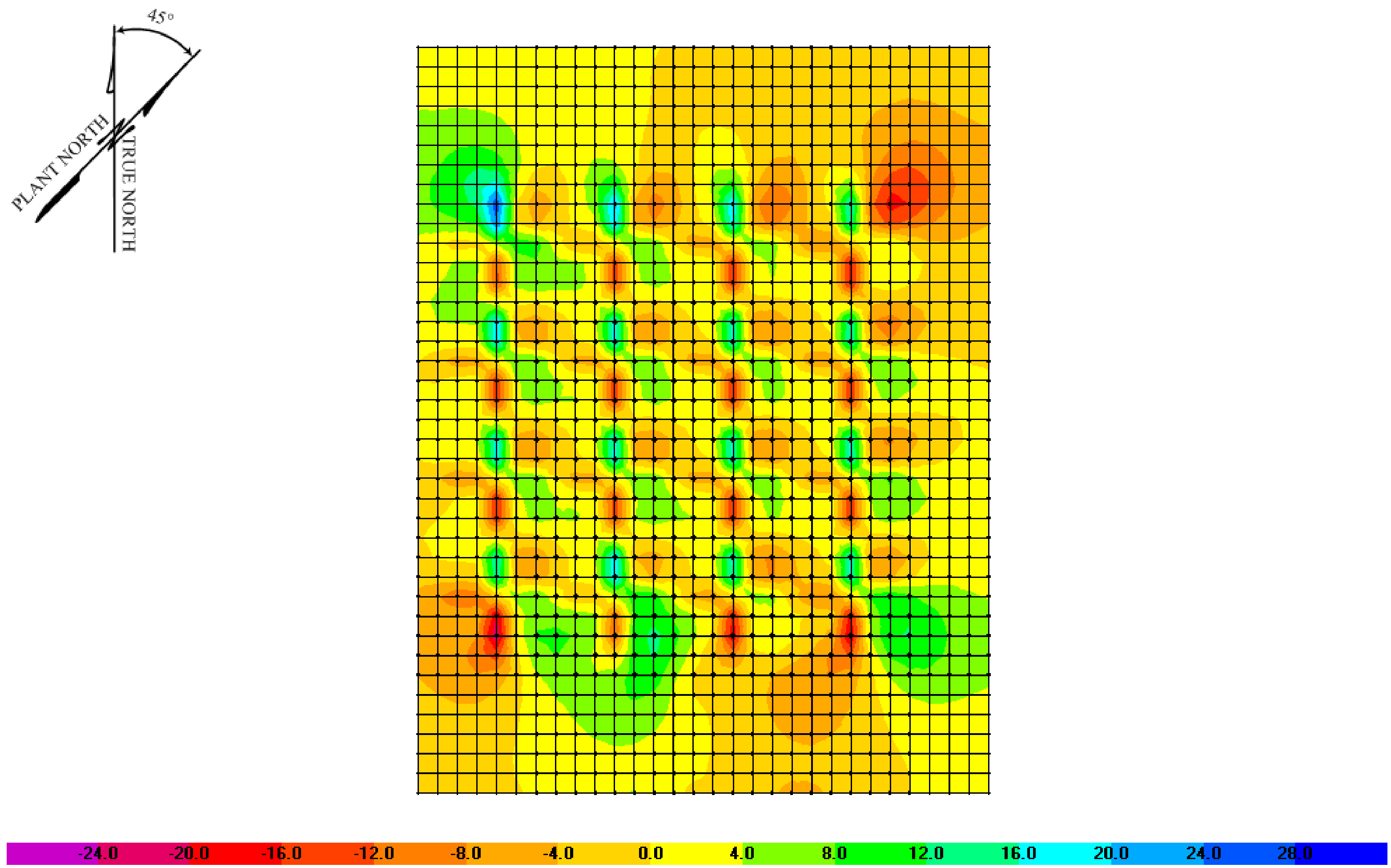
(MIN = -77.791 (k-ft), MAX = 135.243 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 5 (DL_Center+1(HX+HX_Center)+0.4(HY+HY_Center)-0.4(VZ+VZ_Center))



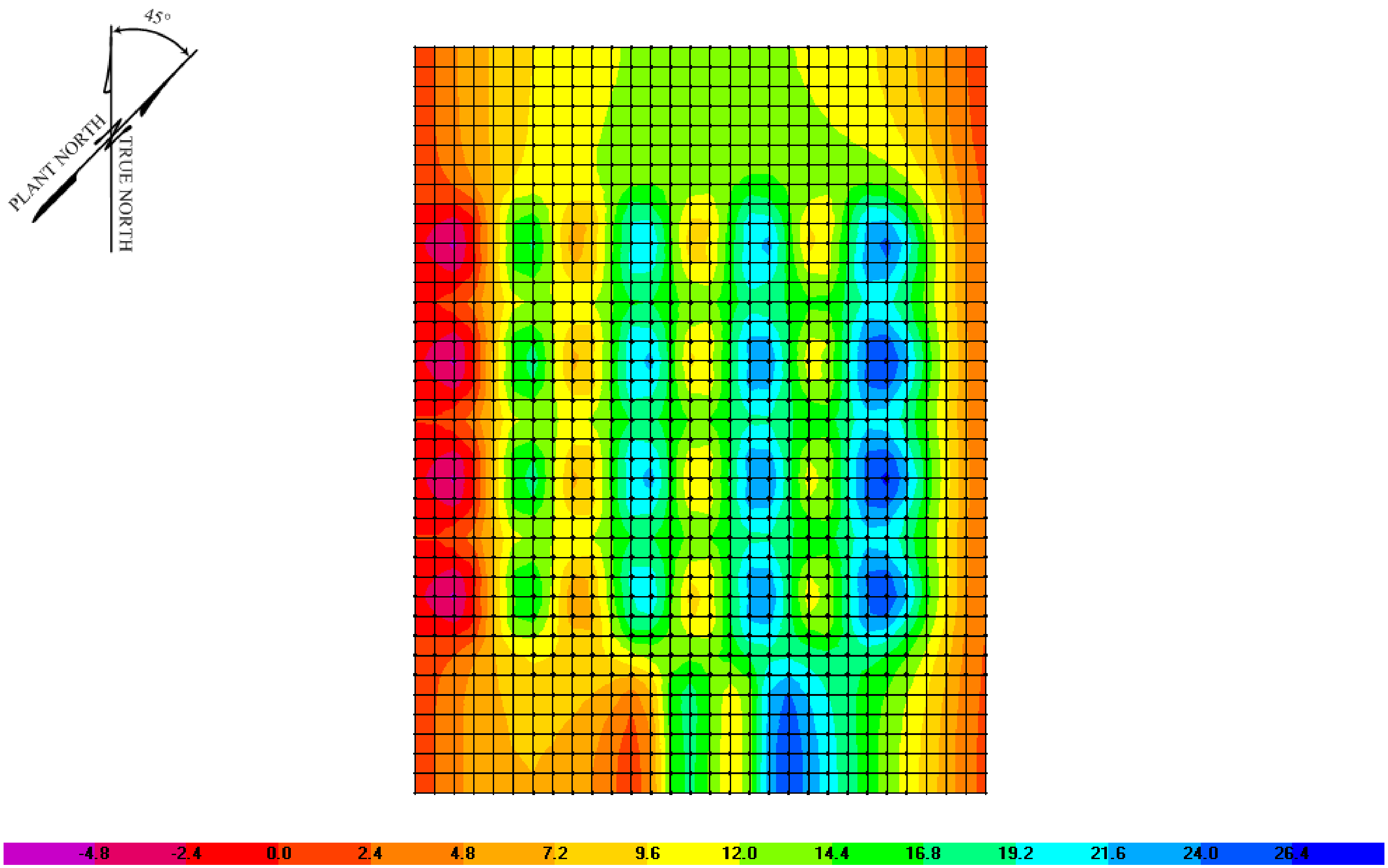
(MIN = -44.178 (k-ft), MAX = 97.015 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 5 (DL_Center+1(HX+HX_Center)+0.4(HY+HY_Center)-0.4(VZ+VZ_Center))



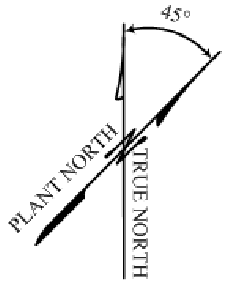
(MIN = -26.727 (k-ft), MAX = 29.317 (k-ft))

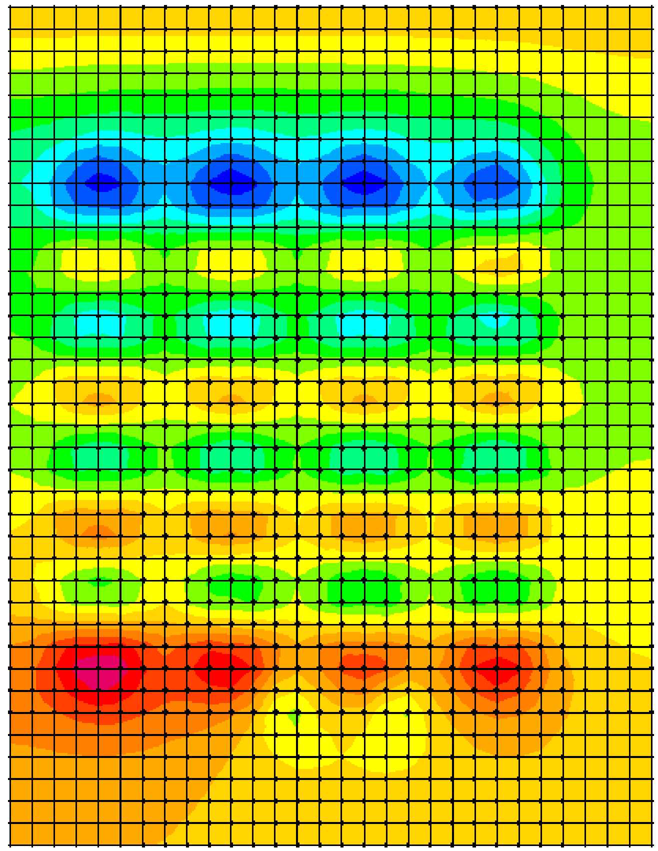
3 ft. Thick Resultant M12 Diagram - Combination 5 (DL_Center+1(HX+HX_Center)+0.4(HY+HY_Center)-0.4(VZ+VZ_Center))



(MAX = 27.797 (kips))

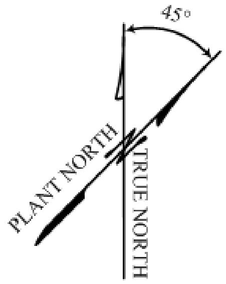
3 ft. Thick Resultant V13 Diagram - Combination 5 (DL_Center+1(HX+HX_Center)+0.4(HY+HY_Center)-0.4(VZ+VZ_Center))

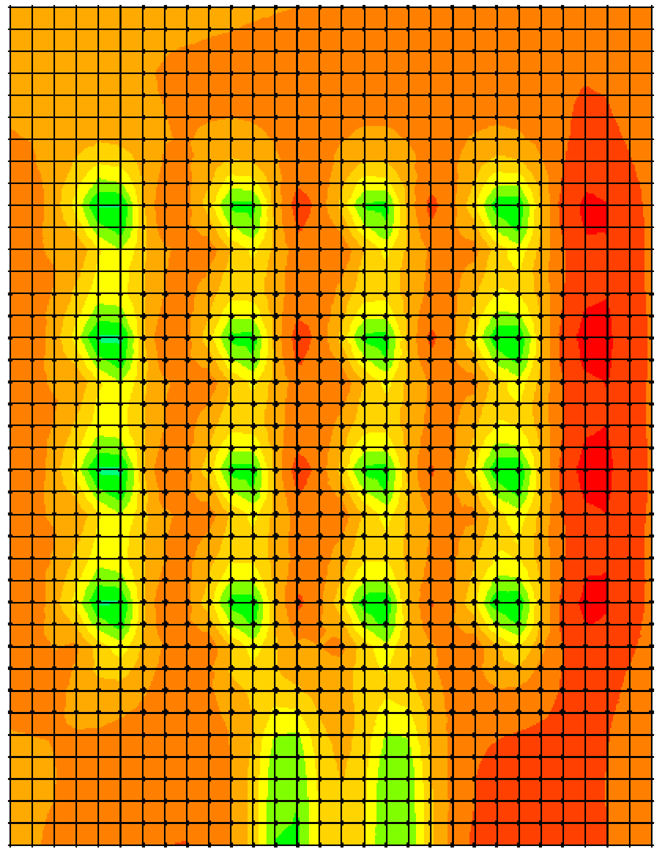




(MAX = 22.485 (kips))

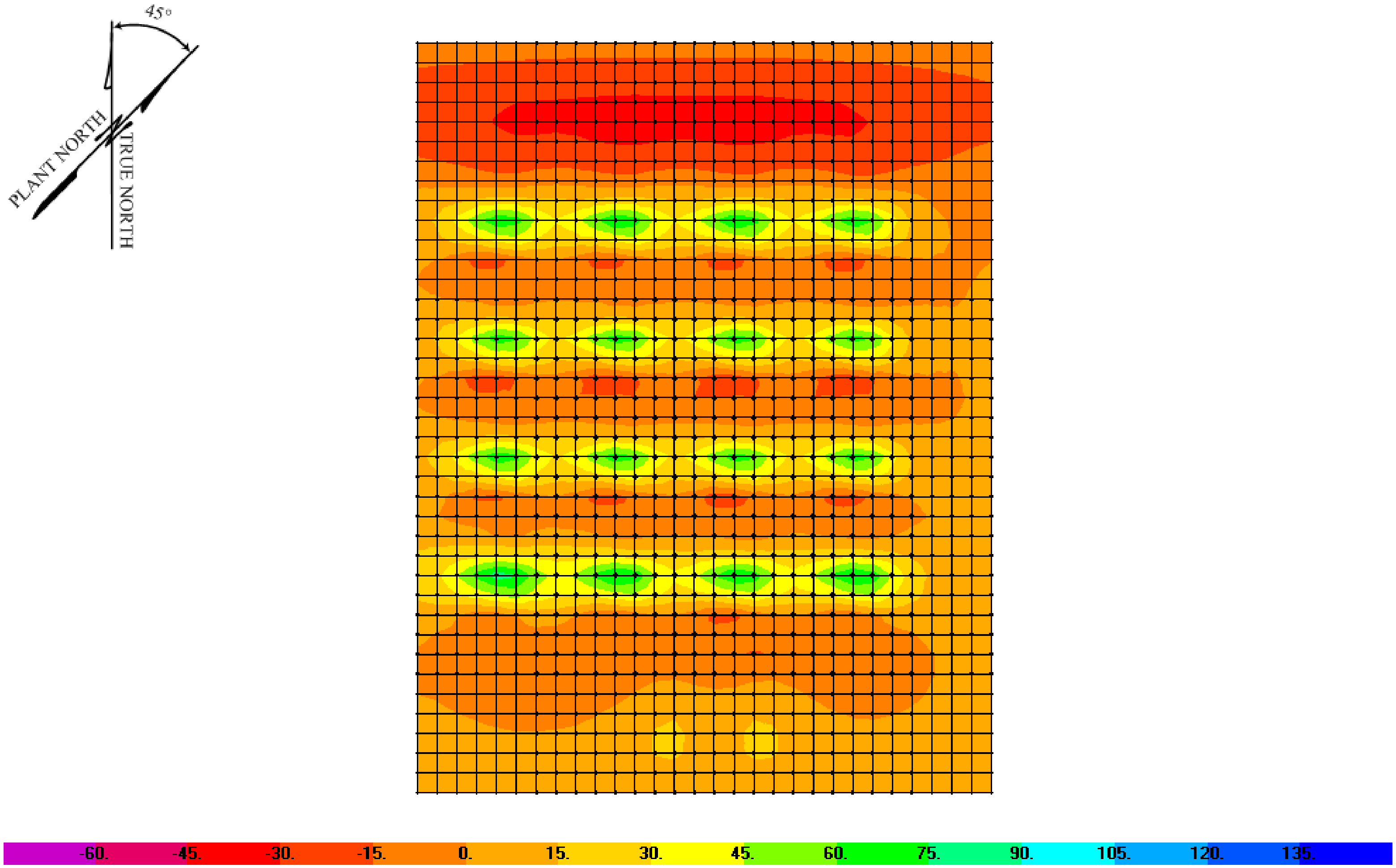
3 ft. Thick Resultant V23 Diagram - Combination 5 (DL_Center+1(HX+HX_Center)+0.4(HY+HY_Center)-0.4(VZ+VZ_Center))





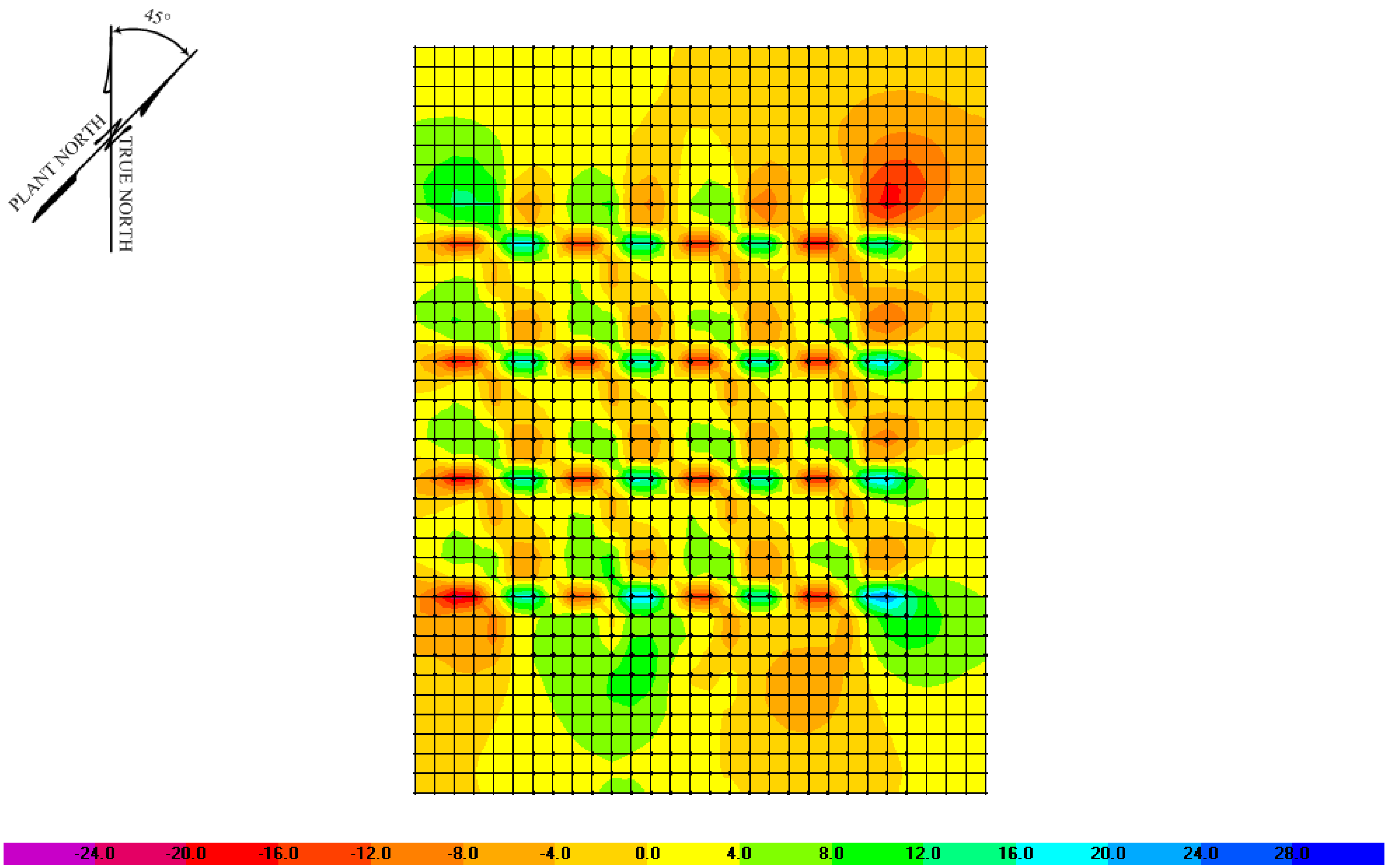
(MIN = -42.523 (k-ft), MAX = 90.213 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 6 (DL_Center+0.4(HX+HX_Center)+1(HY+HY_Center)-0.4(VZ+VZ_Center))



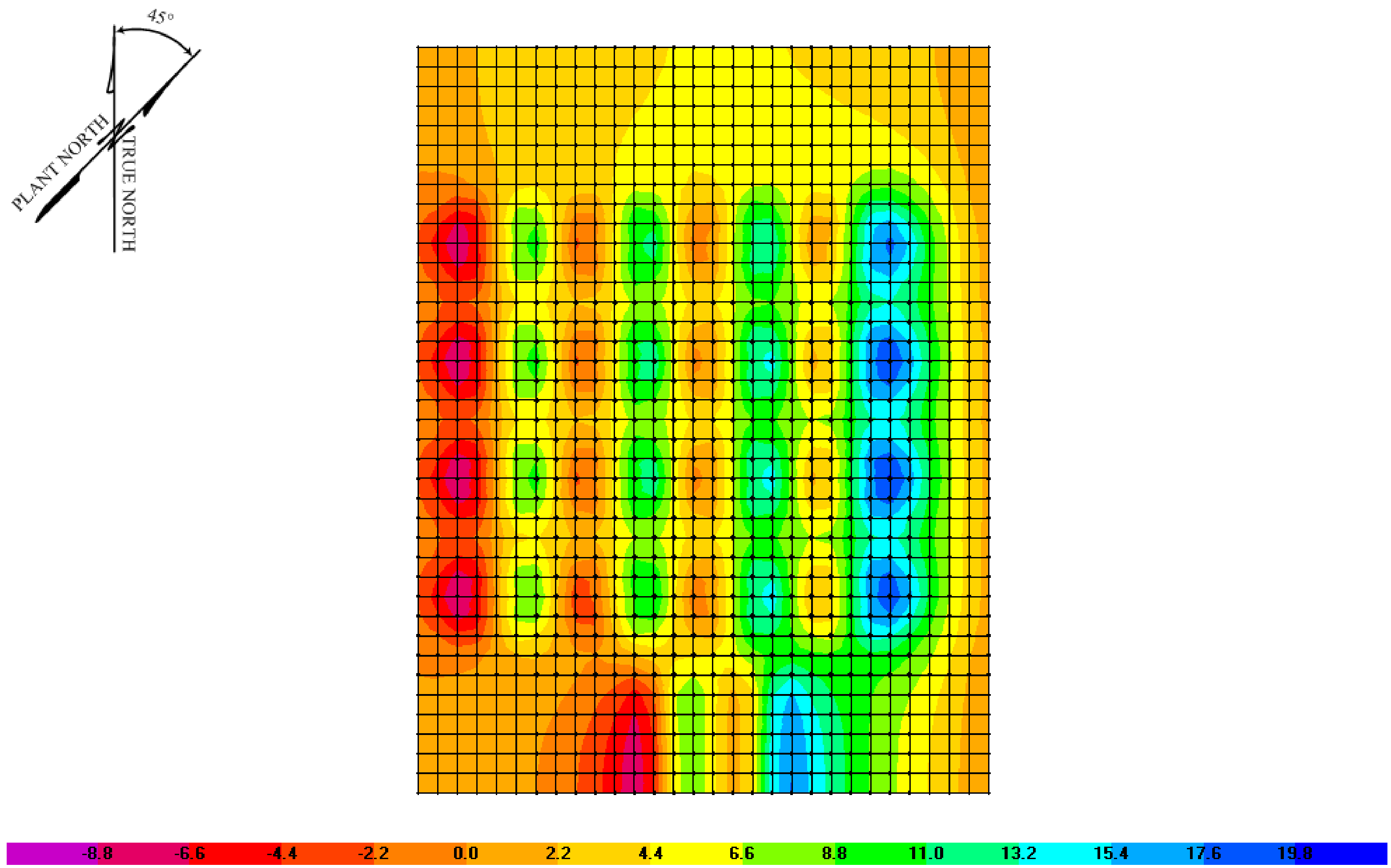
(MIN = -71.325 (k-ft), MAX = 138.213 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 6 (DL_Center+0.4(HX+HX_Center)+1(HY+HY_Center)-0.4(VZ+VZ_Center))



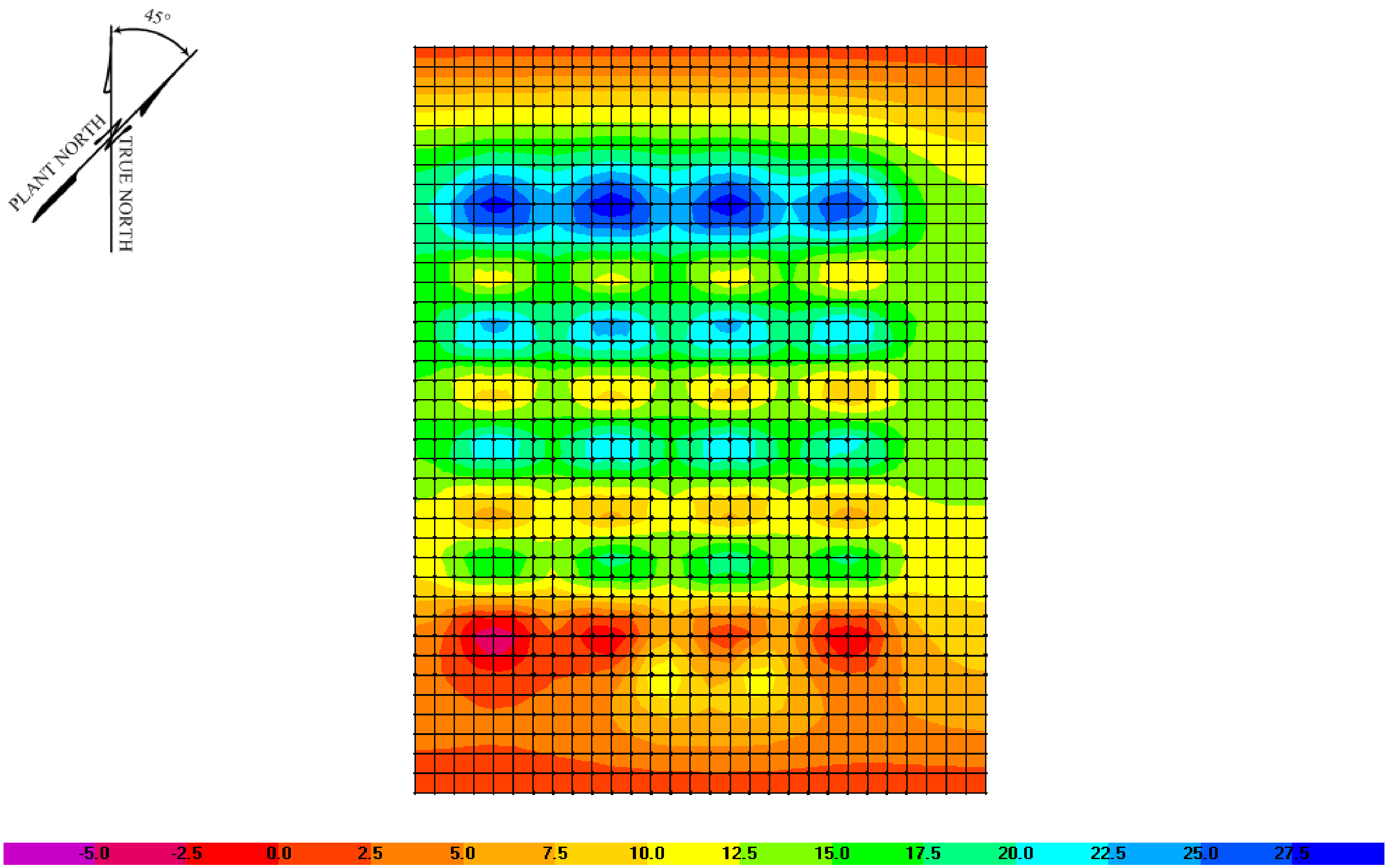
(MIN = -25.962 (k-ft), MAX = 27.422 (k-ft))

3 ft. Thick Resultant M12 Diagram - Combination 6 (DL_Center+0.4(HX+HX_Center)+1(HY+HY_Center)-0.4(VZ+VZ_Center))



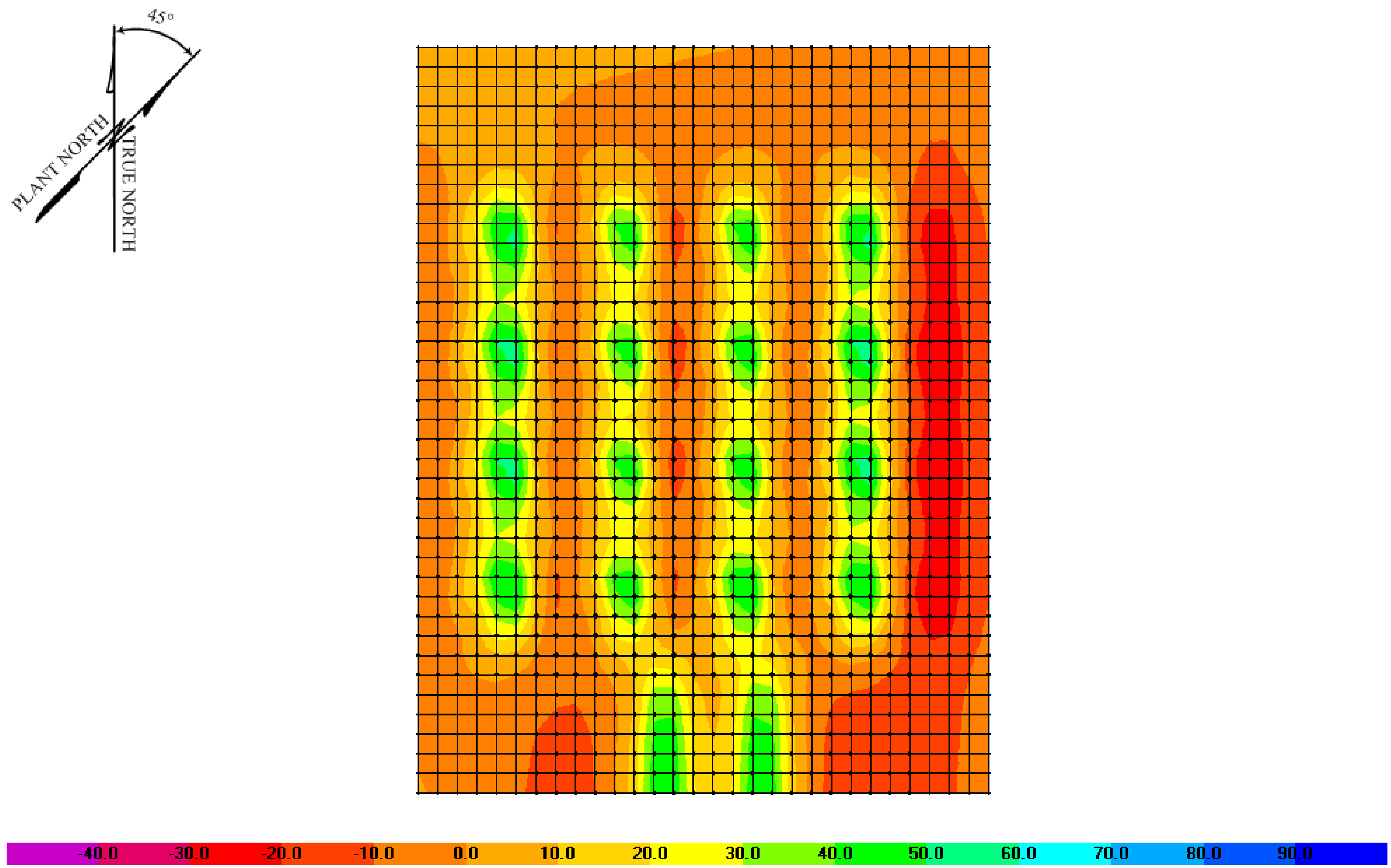
(MAX = 20.810 (kips))

3 ft. Thick Resultant V13 Diagram - Combination 6 (DL_Center+0.4(HX+HX_Center)+1(HY+HY_Center)-0.4(VZ+VZ_Center))



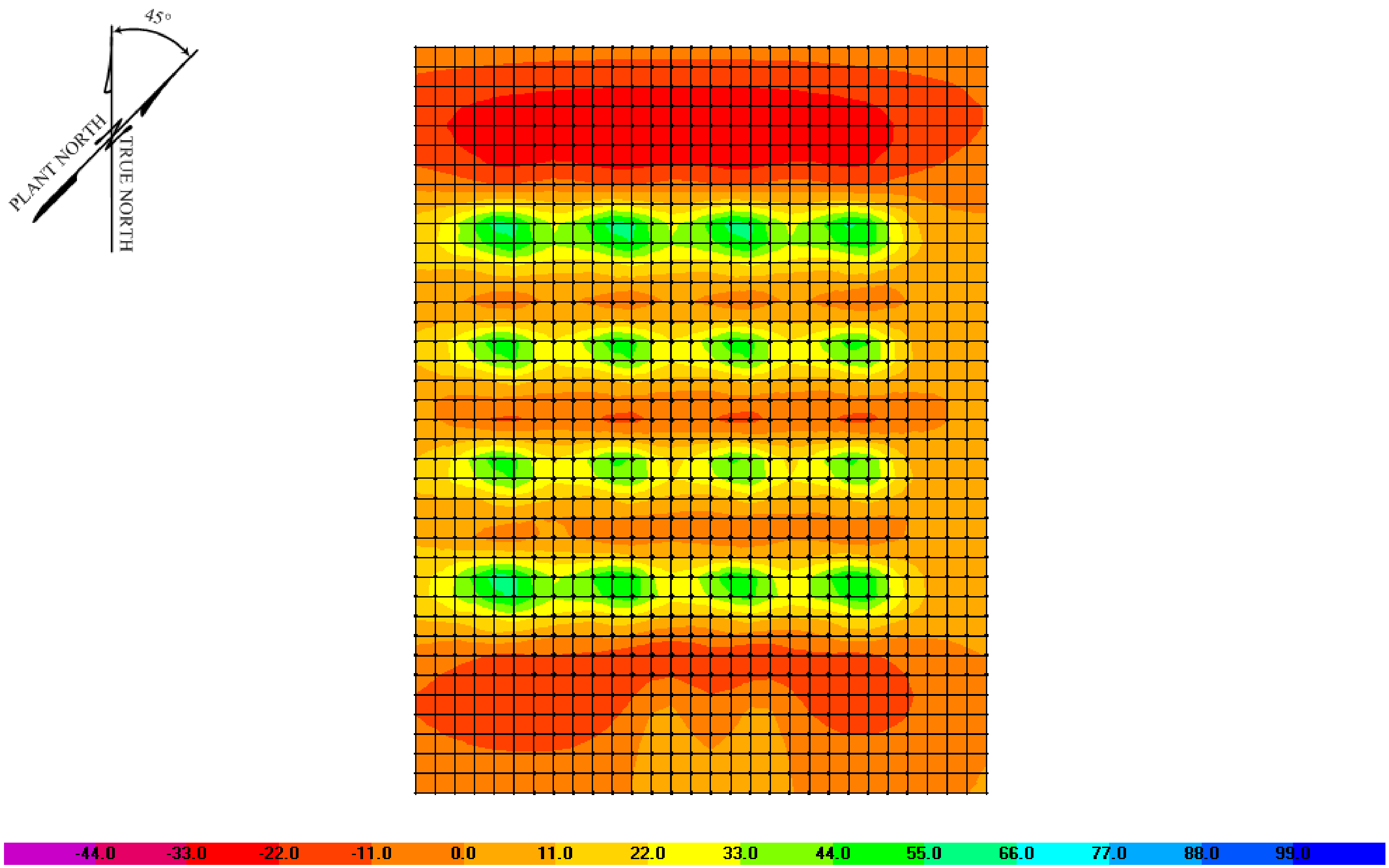
(MAX = 29.932 (kips))

3 ft. Thick Resultant V23 Diagram - Combination 6 (DL_Center+0.4(HX+HX_Center)+1(HY+HY_Center)-0.4(VZ+VZ_Center))



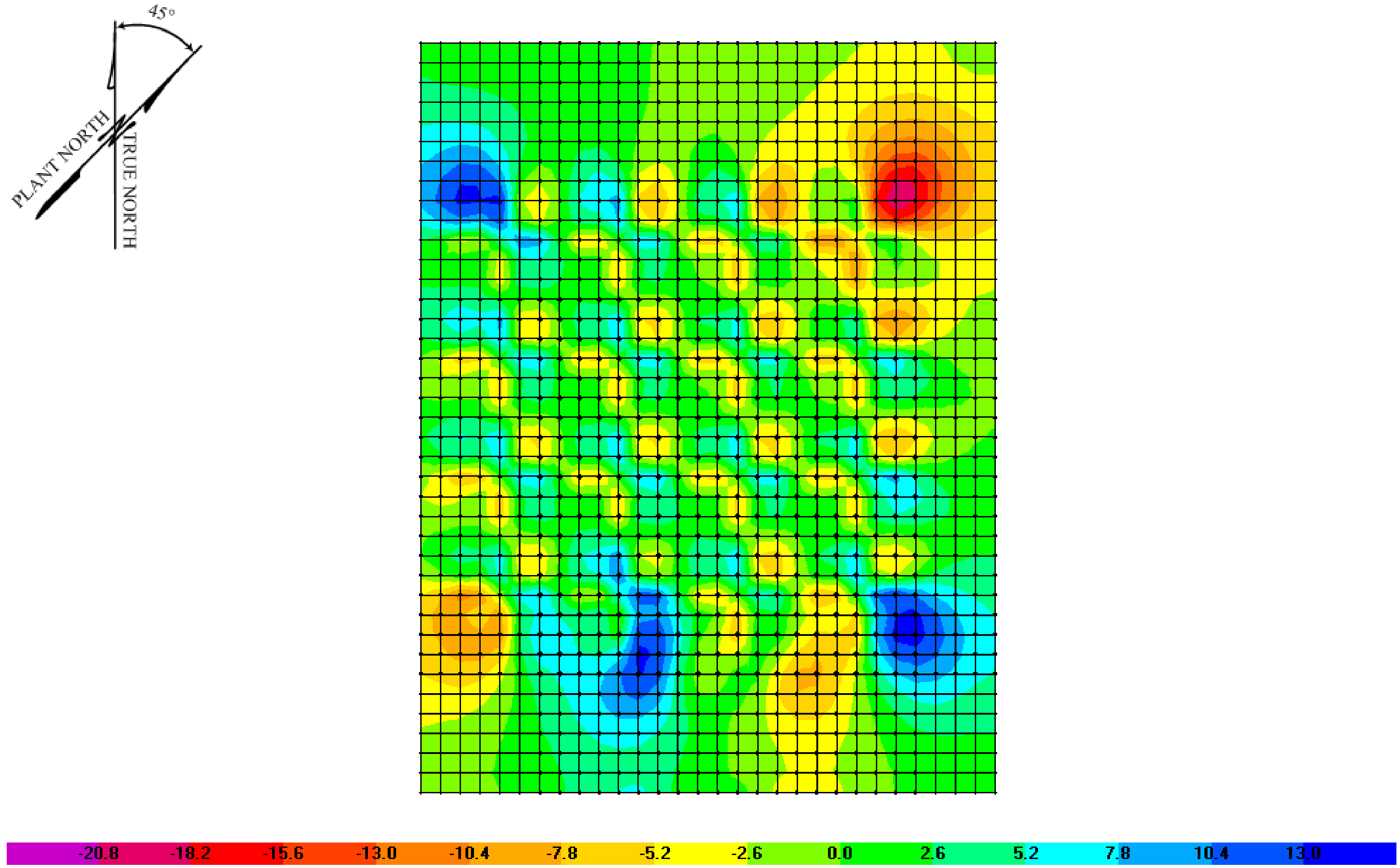
(MIN = -46.371 (k-ft), MAX = 96.328 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 7 (DL_Center+0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))



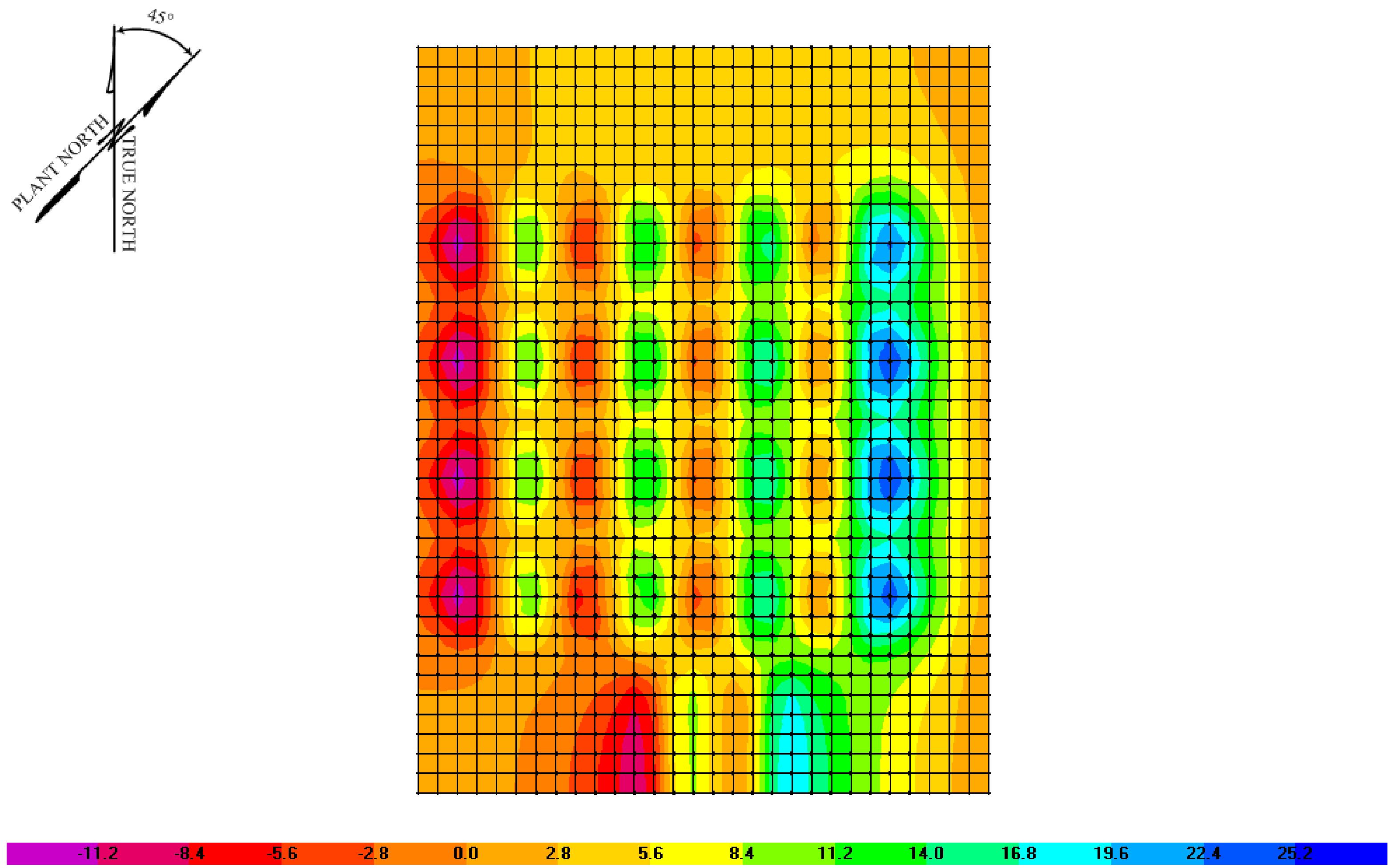
(MIN = -49.751 (k-ft), MAX = 103.502 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 7 (DL_Center+0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))



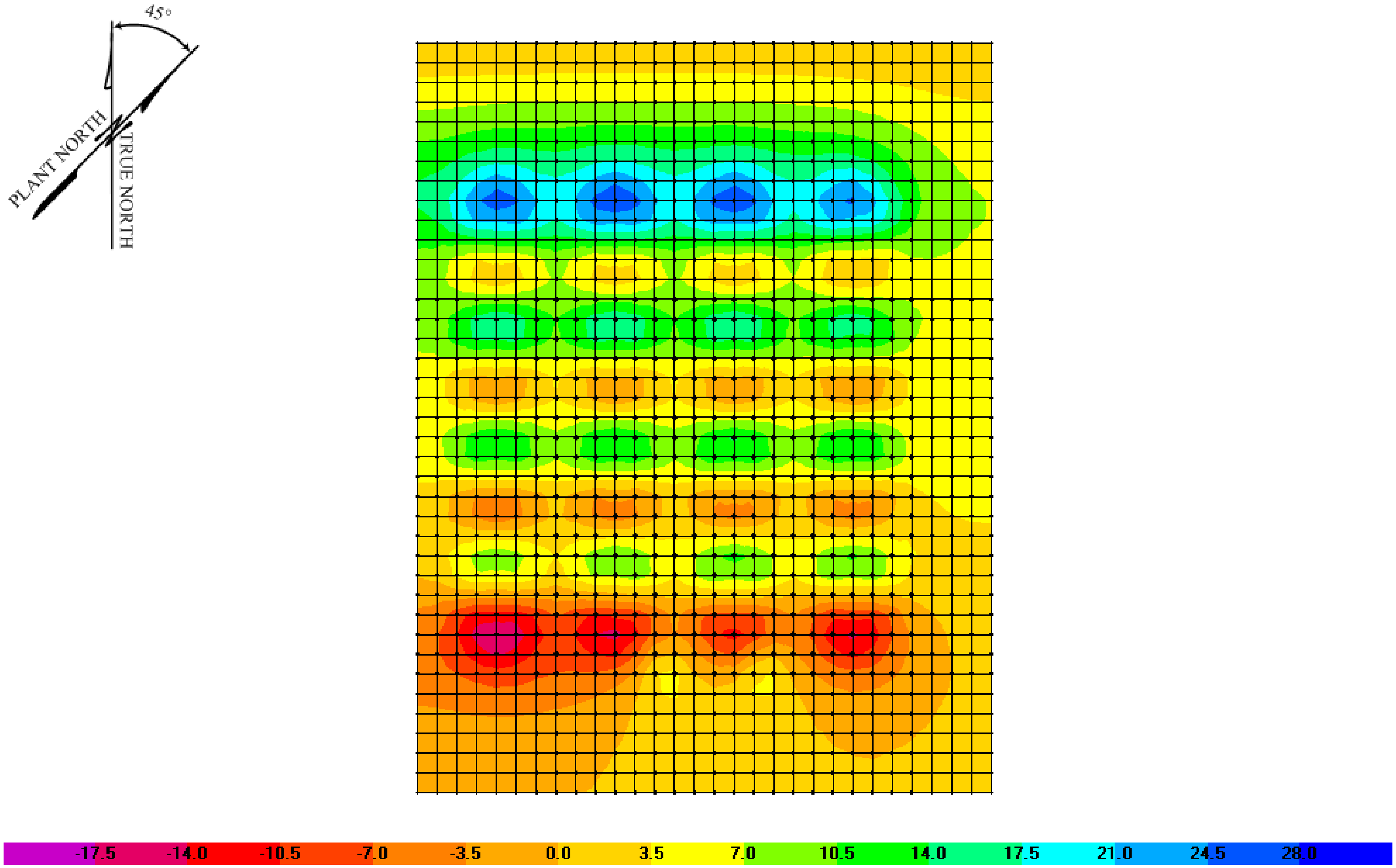
(MIN = -21.168 (k-ft), MAX = 15.117 (k-ft))

3.ft. Thick Resultant M12 Diagram - Combination 7 (DL_Center+0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))



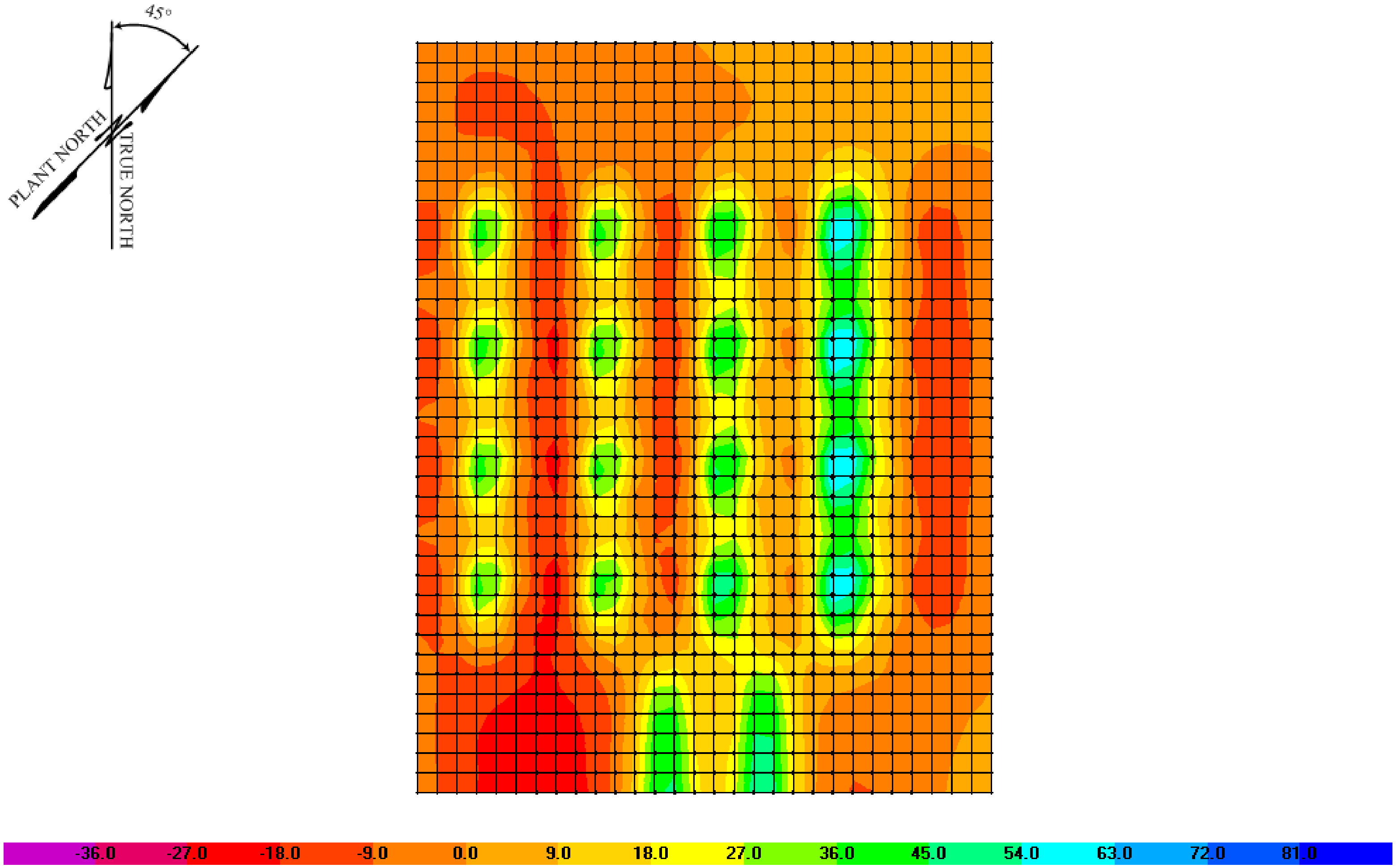
(MAX = 25.364 (kips))

3ft. Thick Resultant V13 Diagram - Combination 7 (DL_Center+0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))



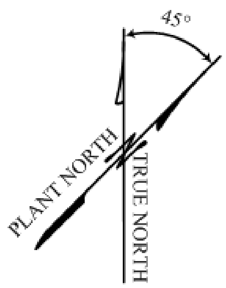
(MAX = 27.879 (kips))

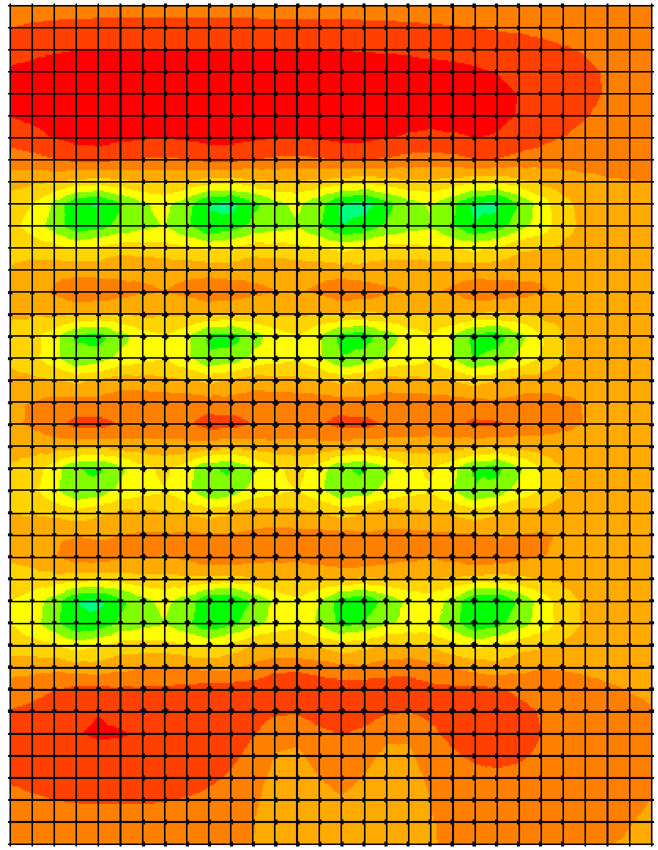
3.ft. Thick Resultant V23 Diagram - Combination 7 (DL_Center+0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))



(MIN = -40.528 (k-ft), MAX = 89.795 (k-ft))

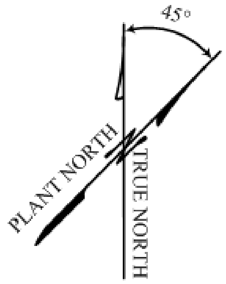
3ft. Thick Resultant M11 Diagram - Combination 8 (DL_Center -0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))

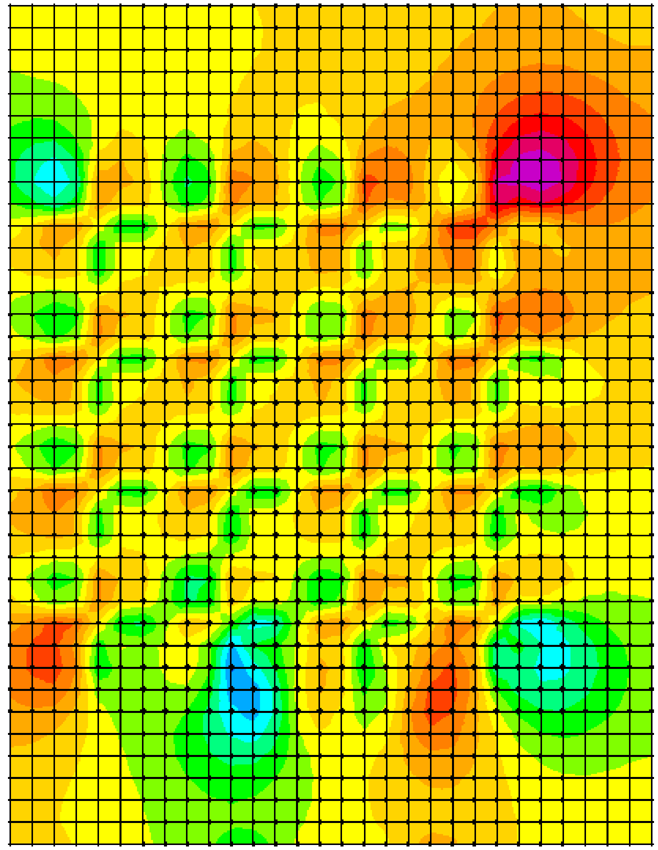




(MIN = -51.506 (k-ft), MAX = 103.916 (k-ft))

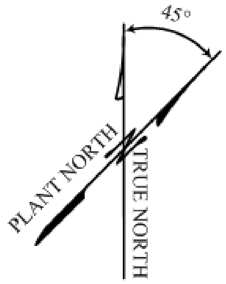
3ft. Thick Resultant M22 Diagram - Combination 8 (DL_Center -0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))

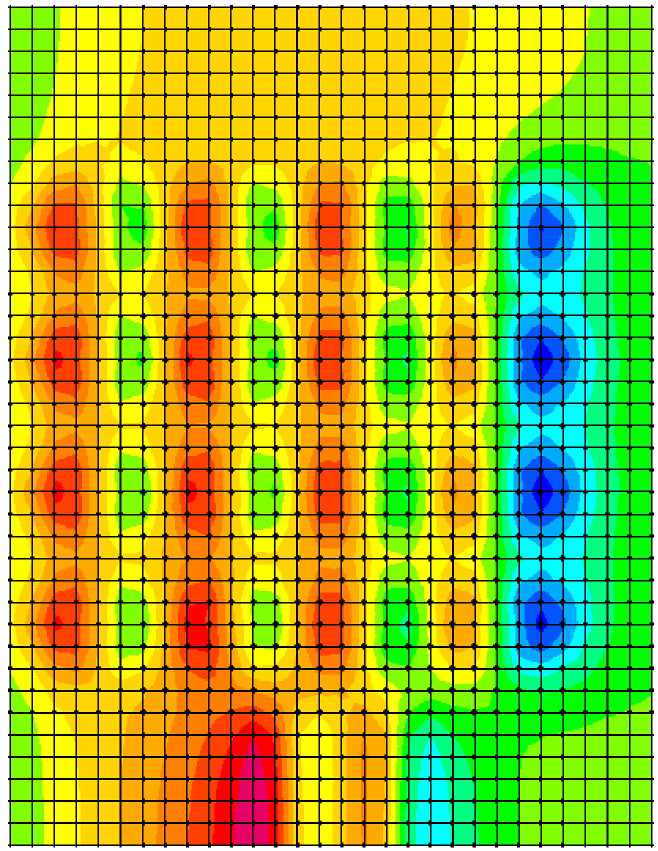




(MIN = -19.361 (k-ft), MAX = 18.834 (k-ft))

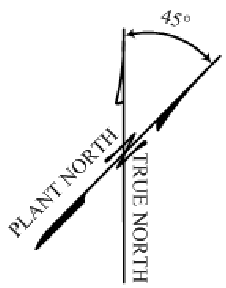
3ft. Thick Resultant M12 Diagram - Combination 8 (DL_Center -0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))

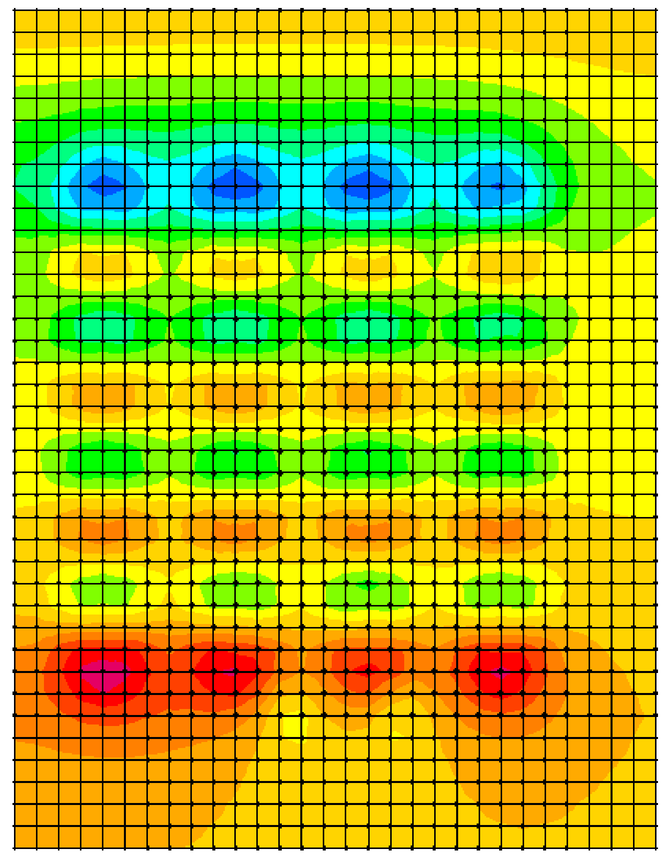




(MAX = 24.354 (kips))

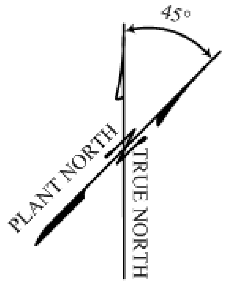
3ft. Thick Resultant V13 Diagram - Combination 8 (DL_Center -0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))

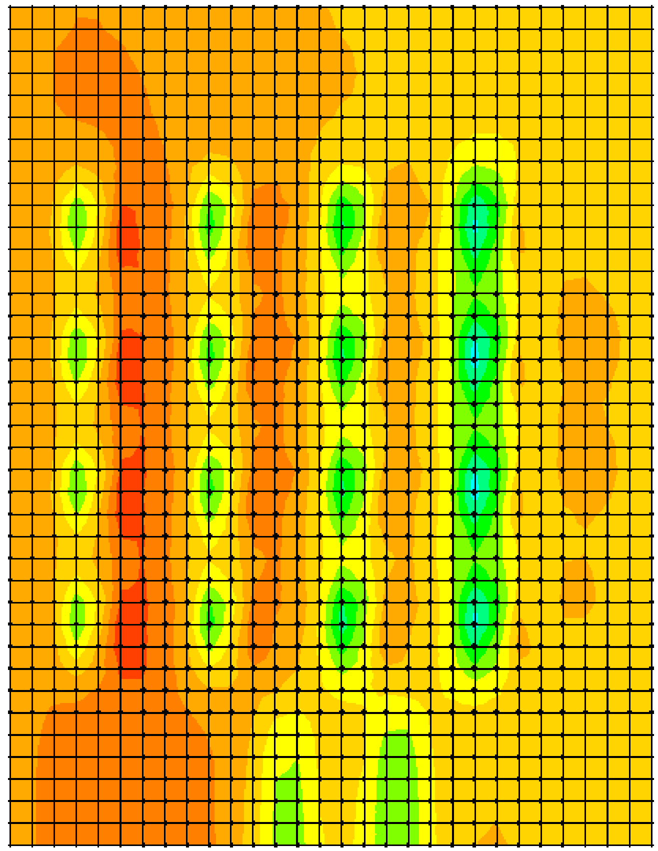




(MAX = 27.870 (kips))

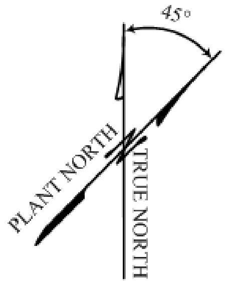
3ft. Thick Resultant V23 Diagram - Combination 8(DL_Center -0.4(HX+HX_Center)+ 0.4 (HY+HY_Center) -1 (VZ+VZ_Center))

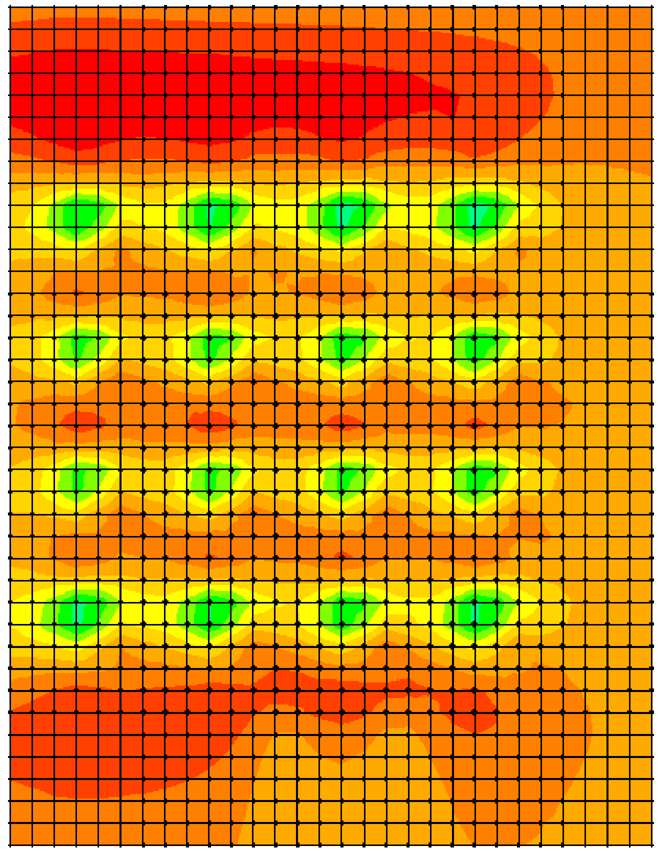




(MIN = -87.885 (k-ft), MAX = 139.269 (k-ft))

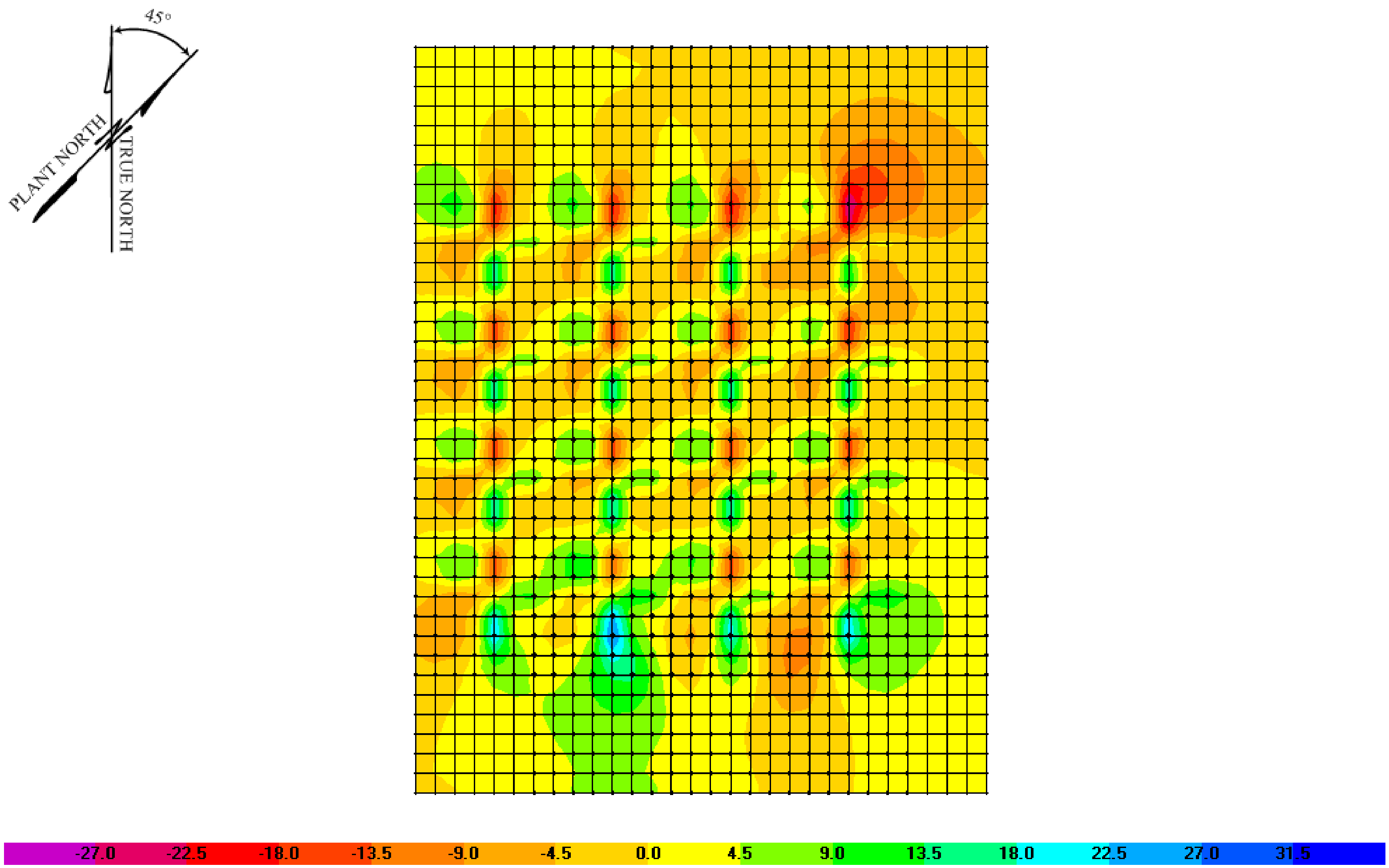
3ft. Thick Resultant M11 Diagram - Combination 9 (DL_Center -1(HX+HX_Center)+ 0.4 (HY+HY_Center) –0.4 (VZ+VZ_Center))





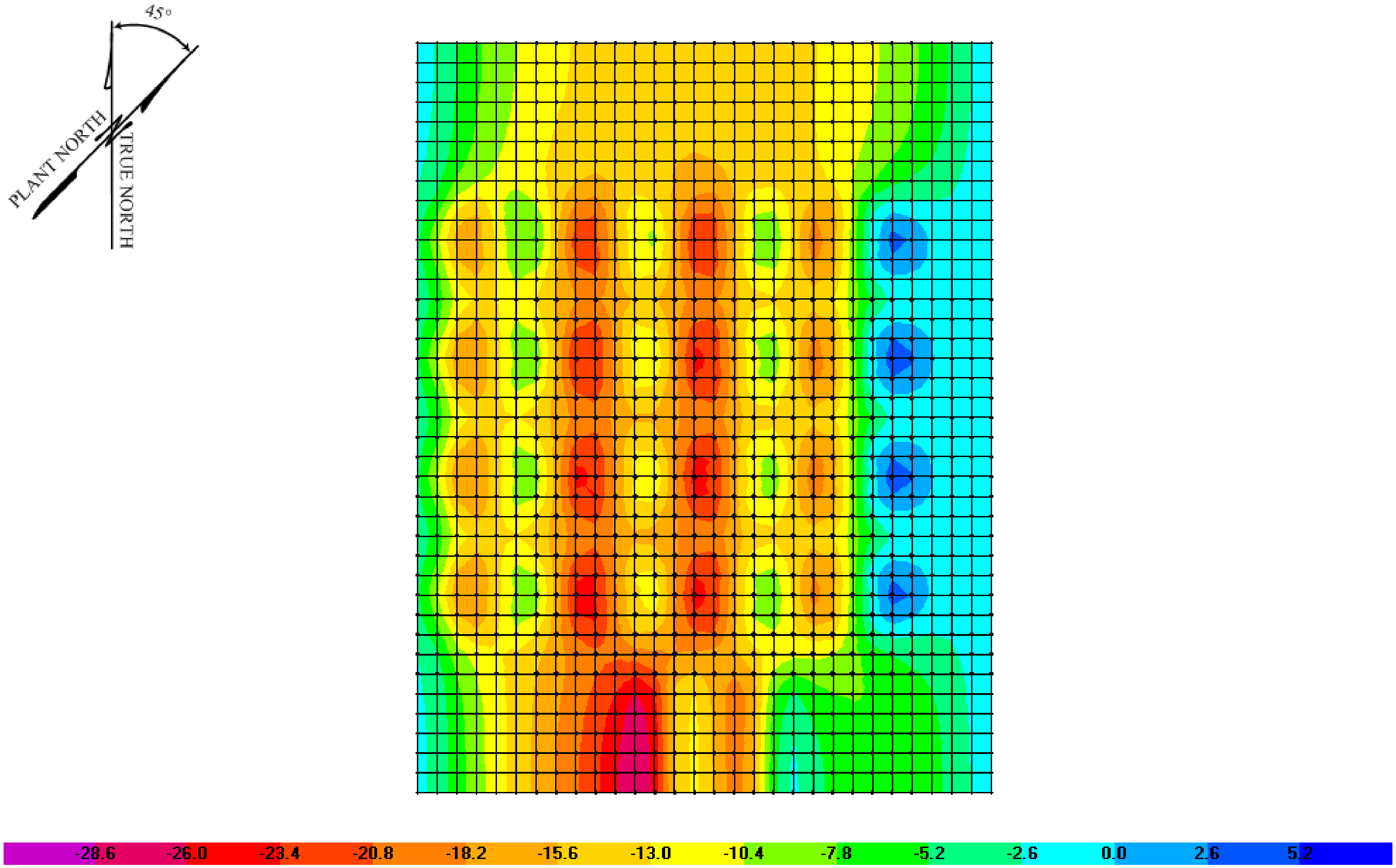
(MIN = -46.229 (k-ft), MAX = 96.845 (k-ft))

3ft. Thick Resultant M22 Diagram - Combination 9 (DL_Center -1(HX+HX_Center)+ 0.4 (HY+HY_Center) –0.4 (VZ+VZ_Center))



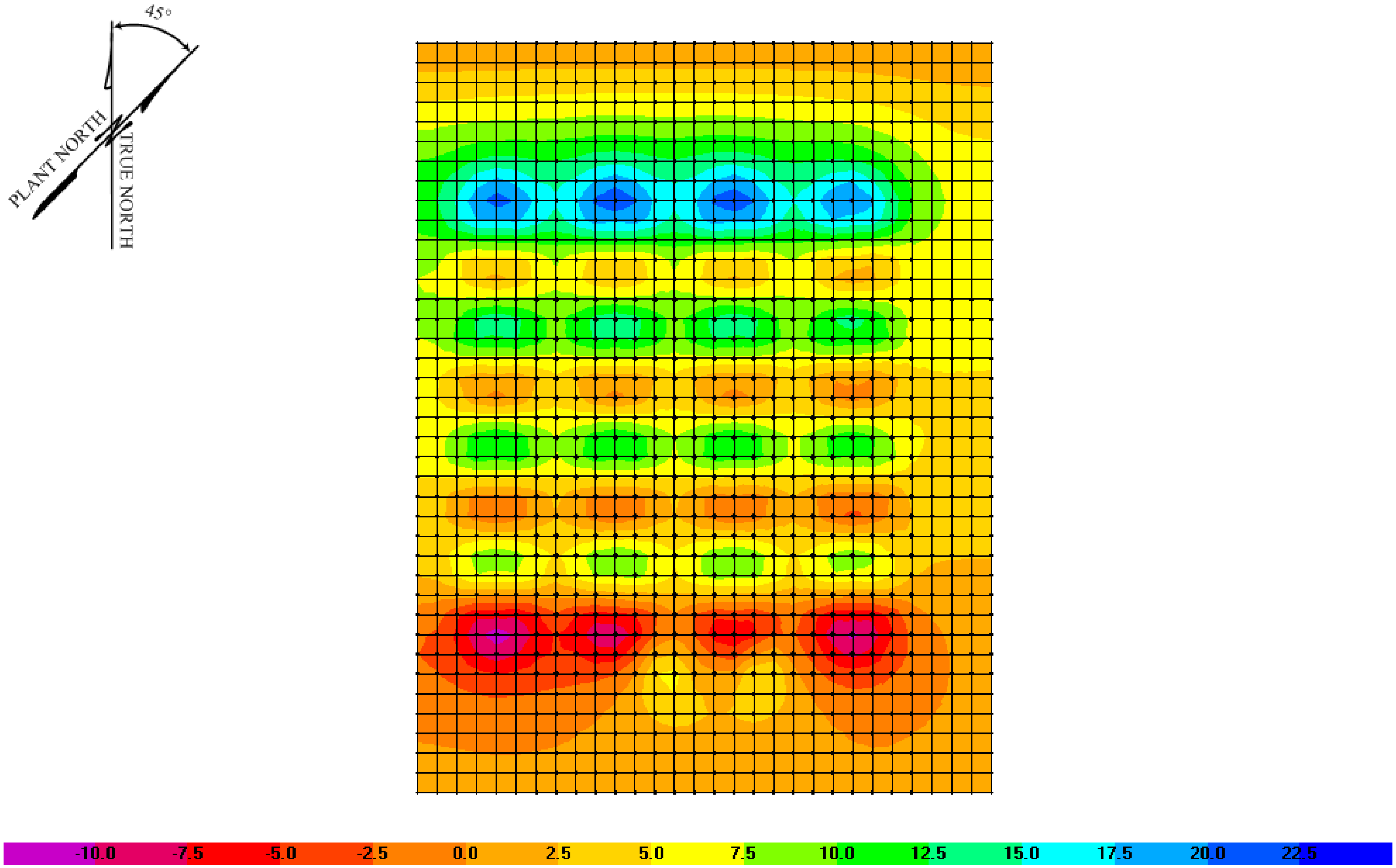
(MIN = -31.289 (k-ft), MAX = 31.181 (k-ft))

3ft. Thick Resultant M12 Diagram - Combination 9 (DL_Center -1(HX+HX_Center)+ 0.4 (HY+HY_Center) –0.4 (VZ+VZ_Center))



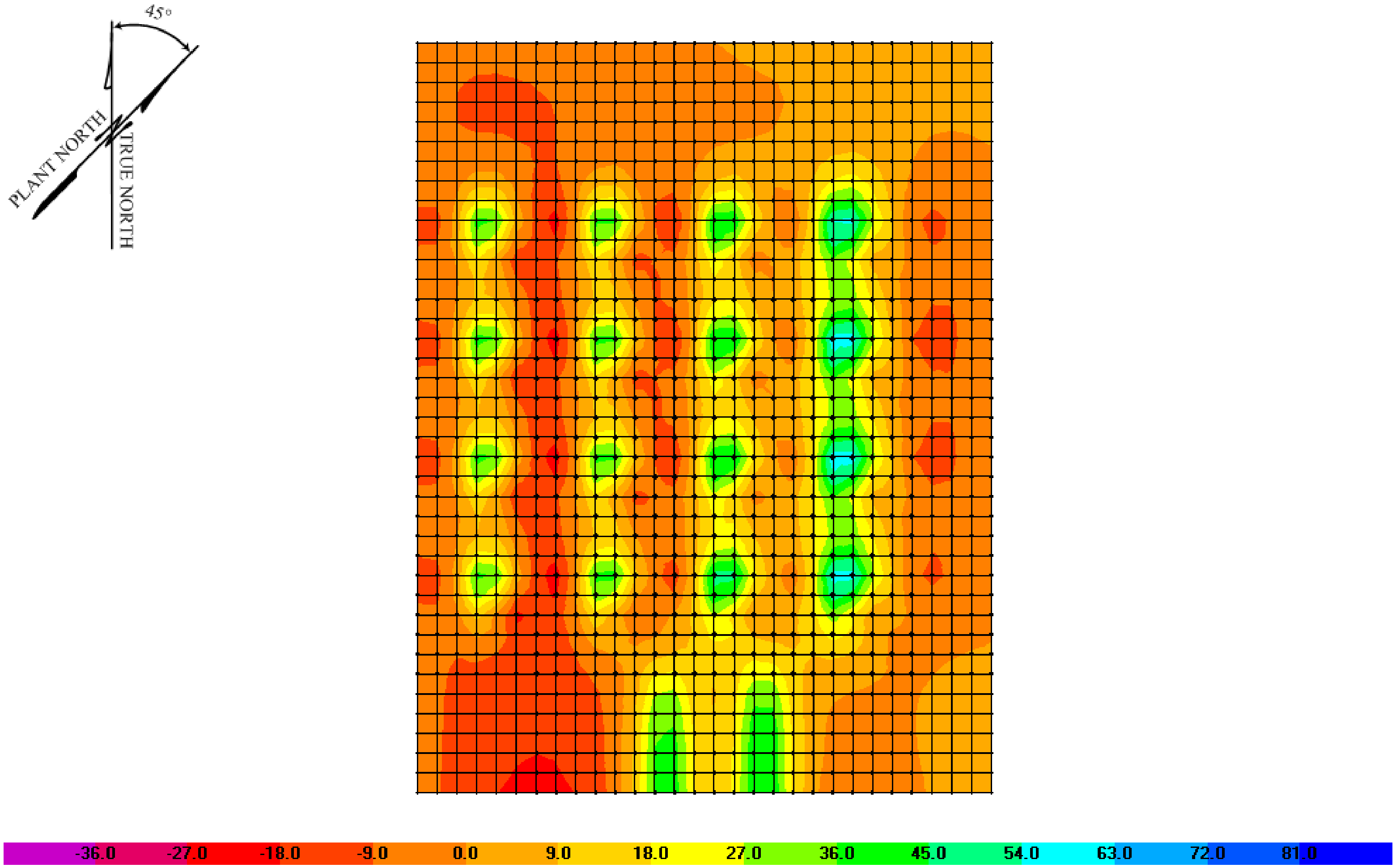
(MAX = 30.329 (kips))

3ft. Thick Resultant V13 Diagram - Combination 9 (DL_Center -1(HX+HX_Center)+ 0.4 (HY+HY_Center) –0.4 (VZ+VZ_Center))



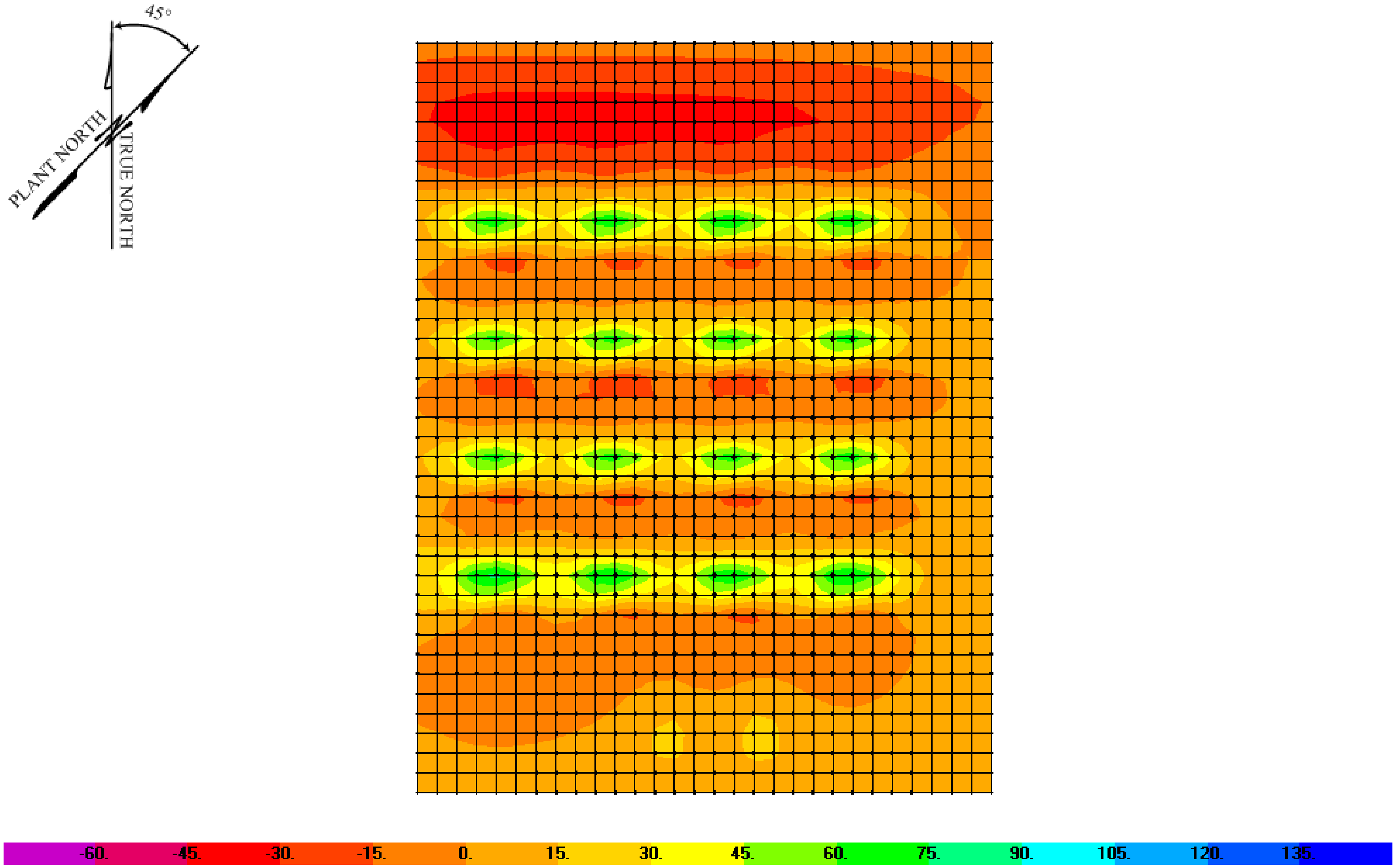
(MAX = 22.435 (kips))

3ft. Thick Resultant V23 Diagram - Combination 9 (DL_Center -1(HX+HX_Center)+ 0.4 (HY+HY_Center) –0.4 (VZ+VZ_Center))



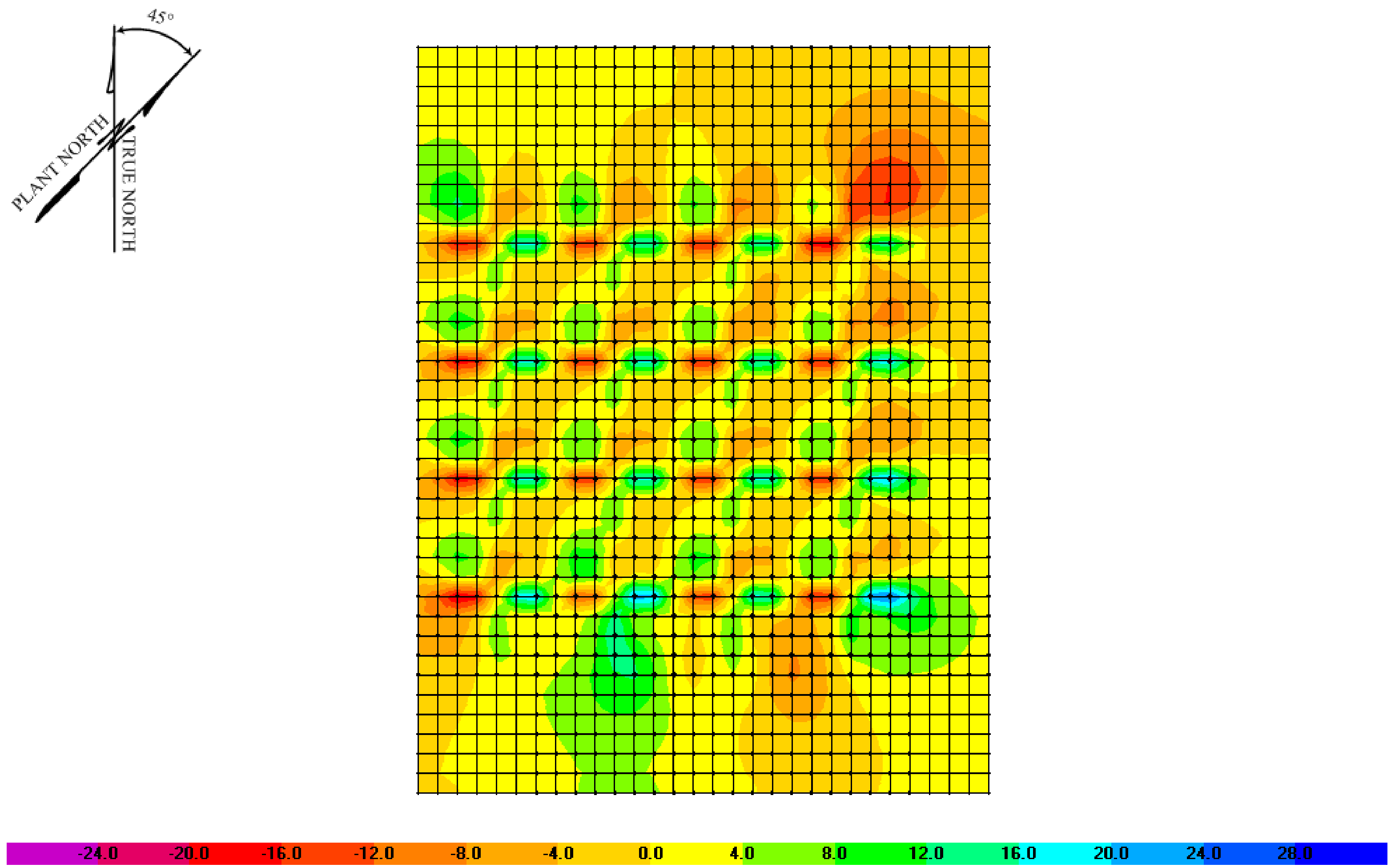
(MIN = -37.752 (k-ft), MAX = 87.434 (k-ft))

3ft. Thick Resultant M11 Diagram - Combination 10 (DL_Center –0.4(HX+HX_Center)+ 1 (HY+HY_Center) –0.4 (VZ+VZ_Center))



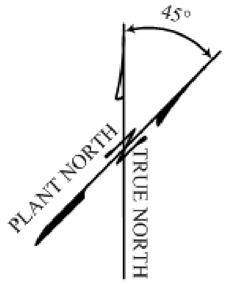
(MIN = -72.604 (k-ft), MAX = 138.189 (k-ft))

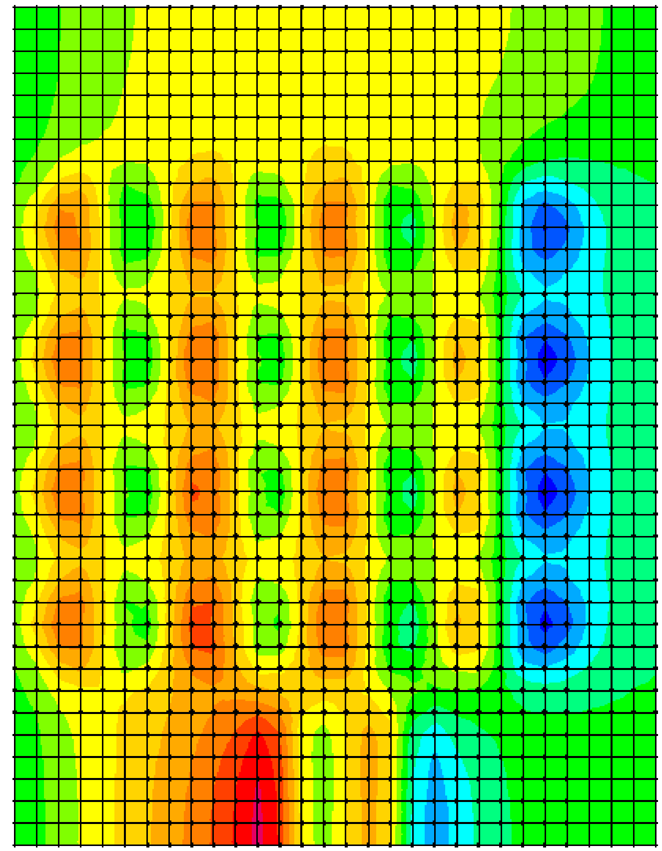
3ft. Thick Resultant M22 Diagram - Combination 10 (DL_Center –0.4(HX+HX_Center)+ 1 (HY+HY_Center) –0.4 (VZ+VZ_Center))



(MIN = -24.628 (k-ft), MAX = 27.968 (k-ft))

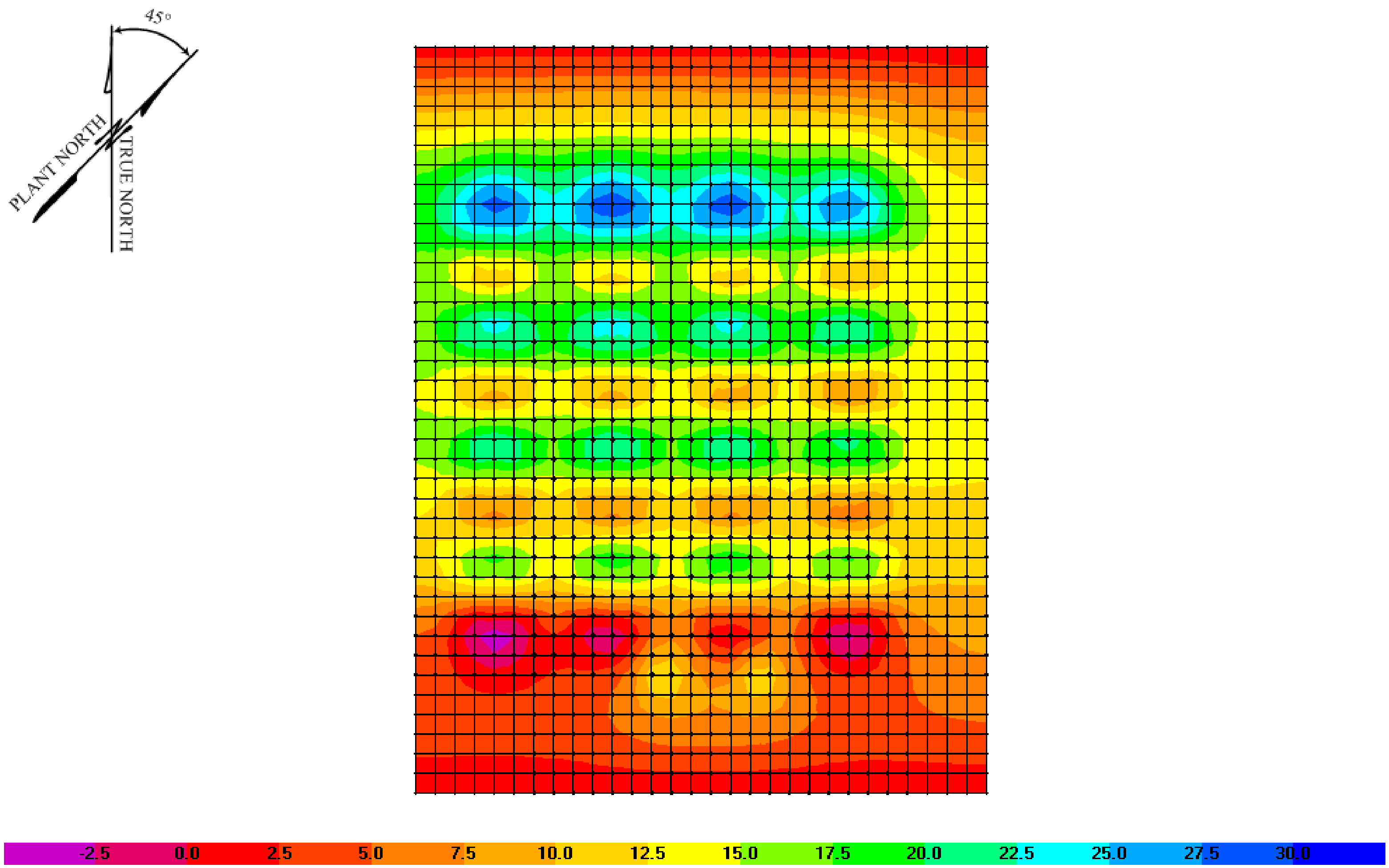
3ft. Thick Resultant M12 Diagram - Combination 10 (DL_Center –0.4(HX+HX_Center)+ 1 (HY+HY_Center) –0.4 (VZ+VZ_Center))





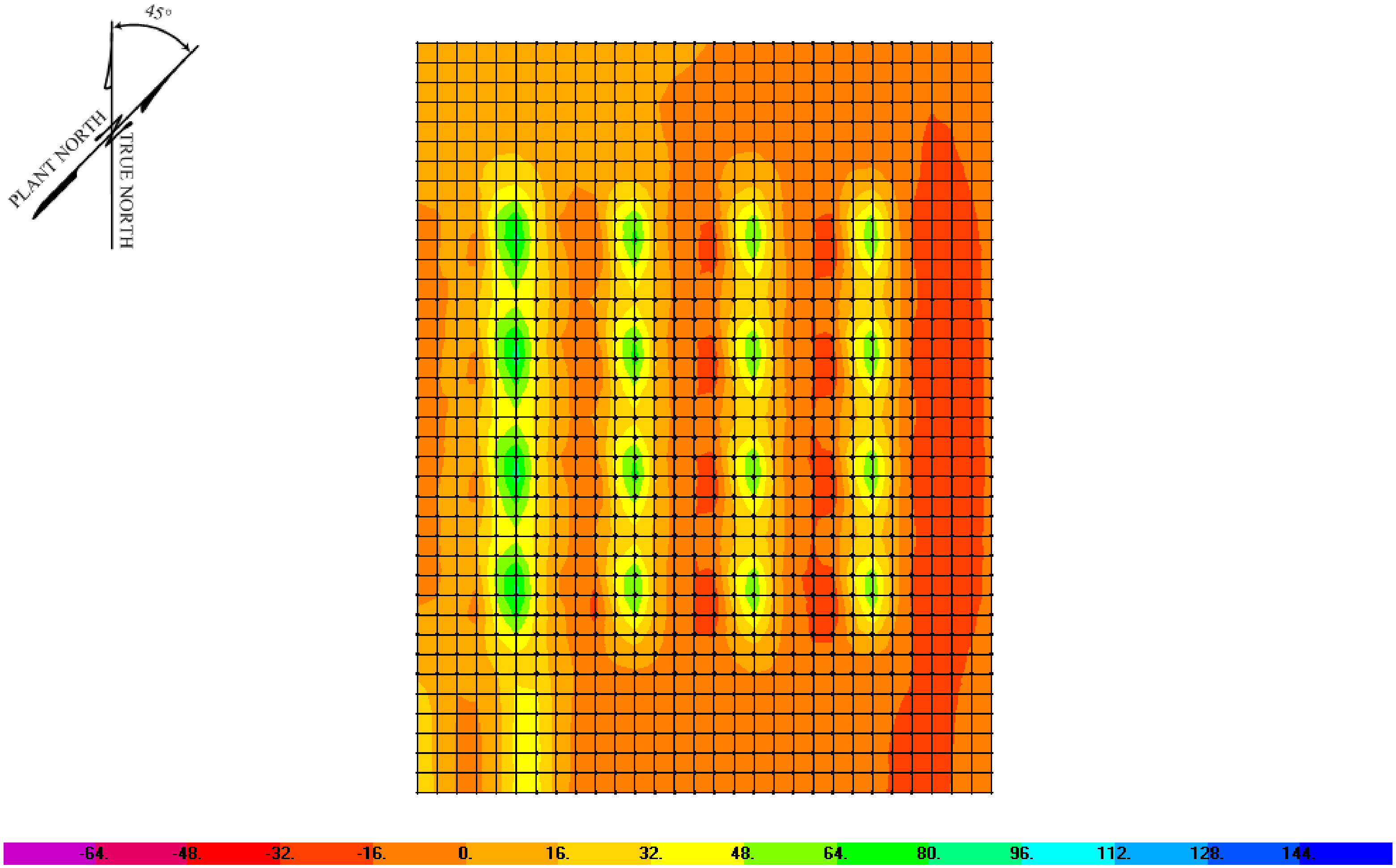
(MAX = 21.624 (kips))

3ft. Thick Resultant V13 Diagram - Combination 10 (DL_Center –0.4(HX+HX_Center)+ 1 (HY+HY_Center) –0.4 (VZ+VZ_Center))



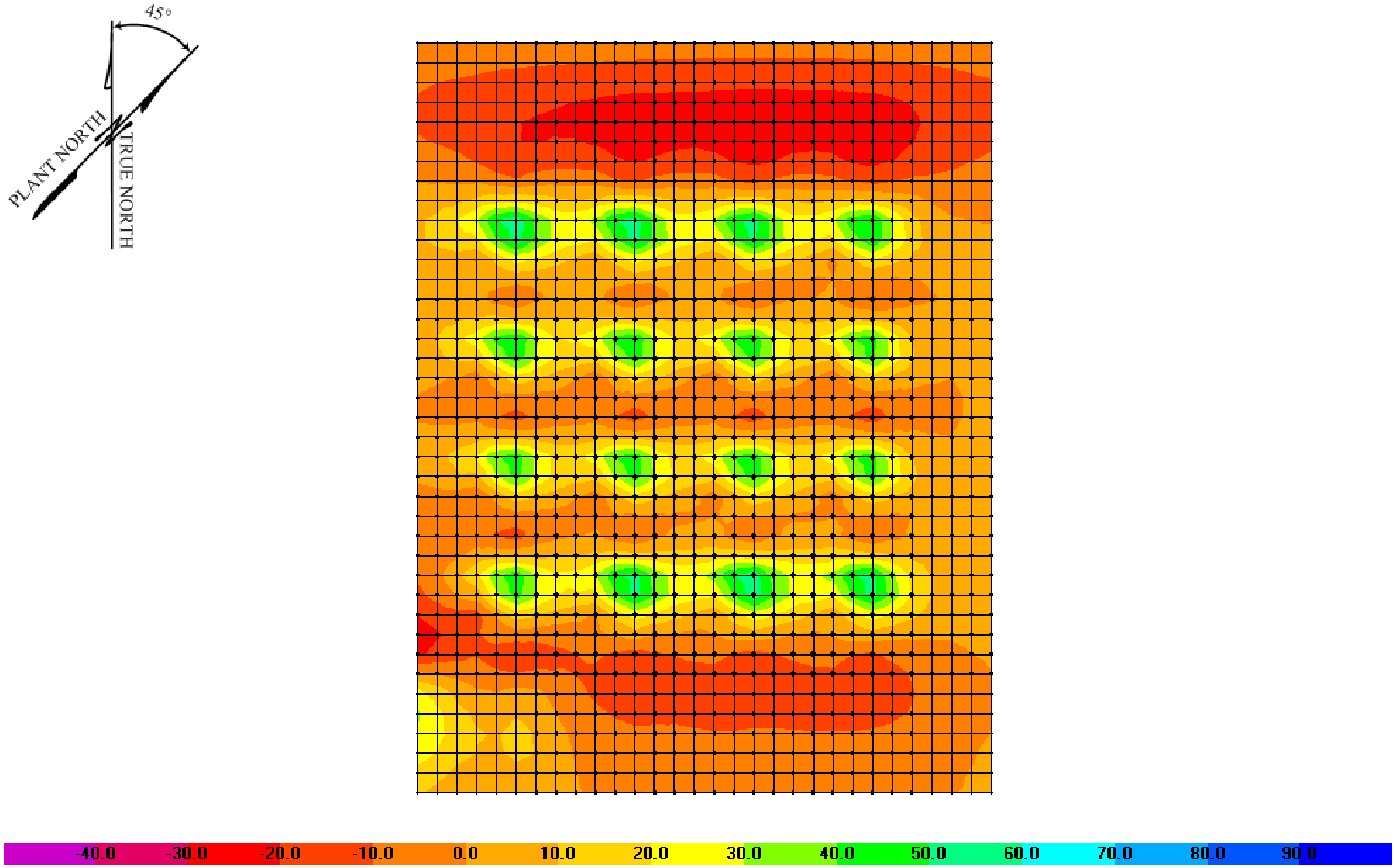
(MAX = 29.928 (kips))

3ft. Thick Resultant V23 Diagram - Combination 10 (DL_Center –0.4(HX+HX_Center)+ 1 (HY+HY_Center) –0.4 (VZ+VZ_Center))



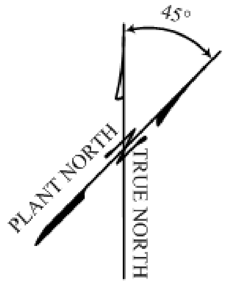
(MIN = -76.548 (k-ft), MAX = 135.533 (k-ft))

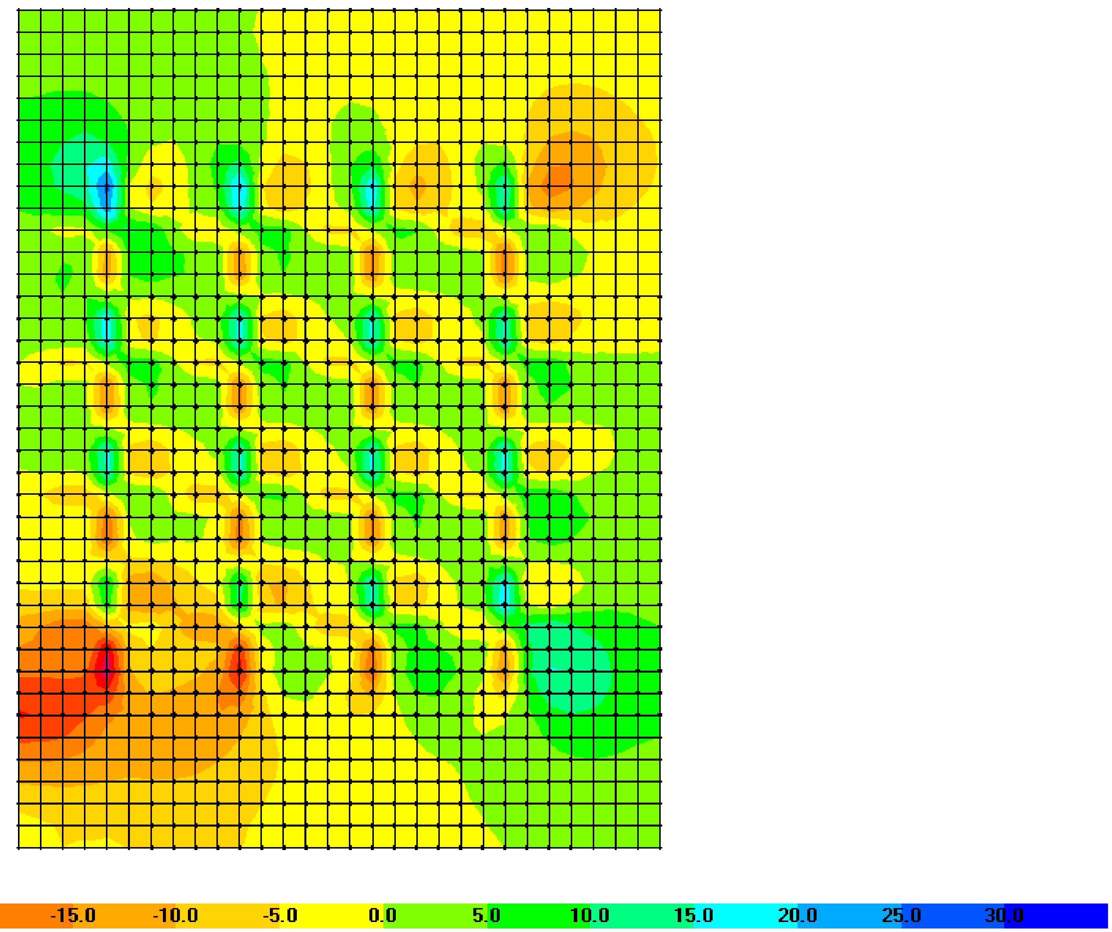
3 ft. Thick Resultant M11 Diagram - Combination 11 (DL_Edge+1(HX+HX_Edge)+0.4(HY+HY_Edge)-0.4(VZ+VZ_Edge))



(MIN = -44.738(k-ft), MAX = 97.088 (k-ft))

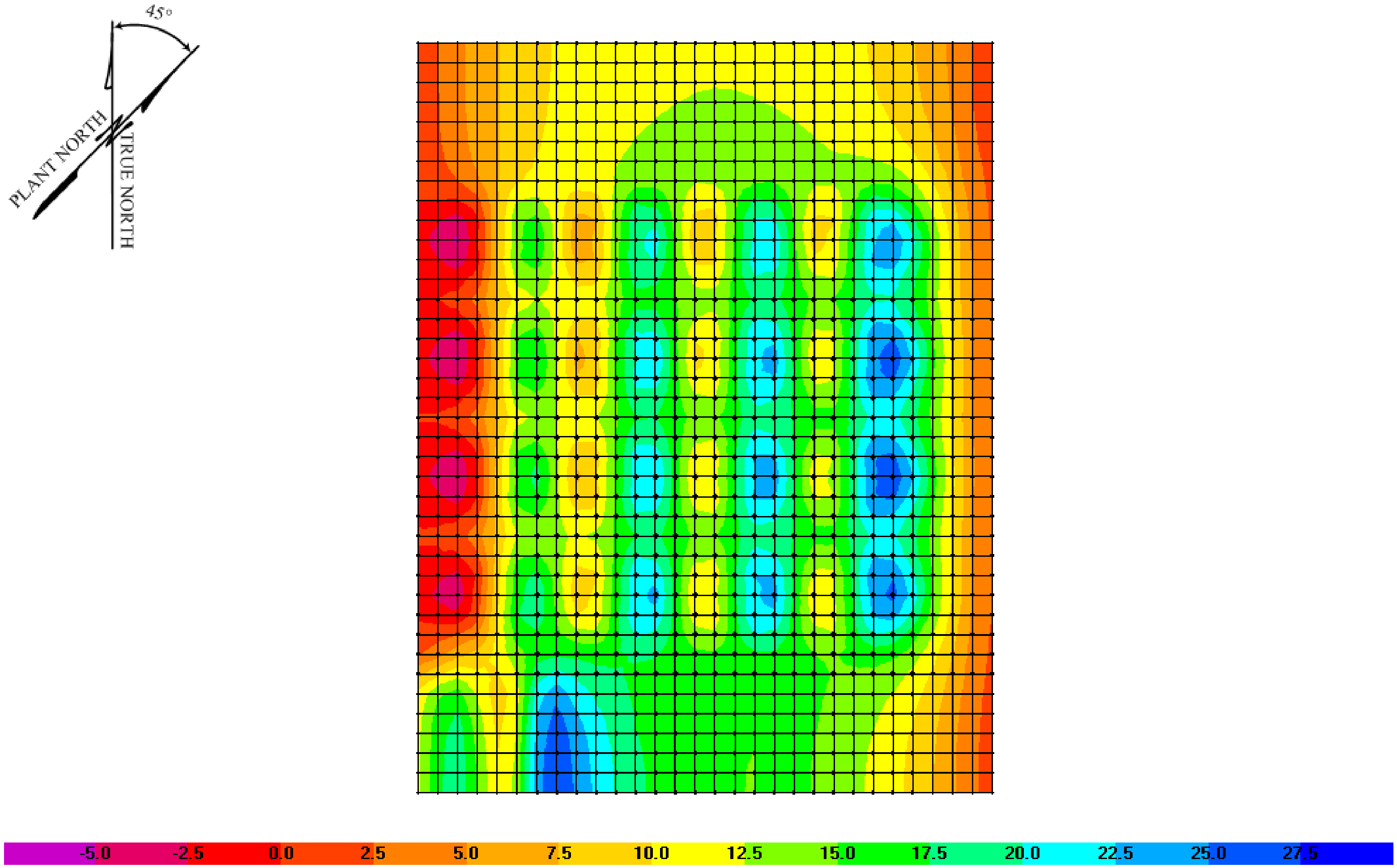
3 ft. Thick Resultant M22 Diagram - Combination 11 (DL_Edge+1(HX+HX_Edge)+0.4(HY+HY_Edge)-0.4(VZ+VZ_Edge))





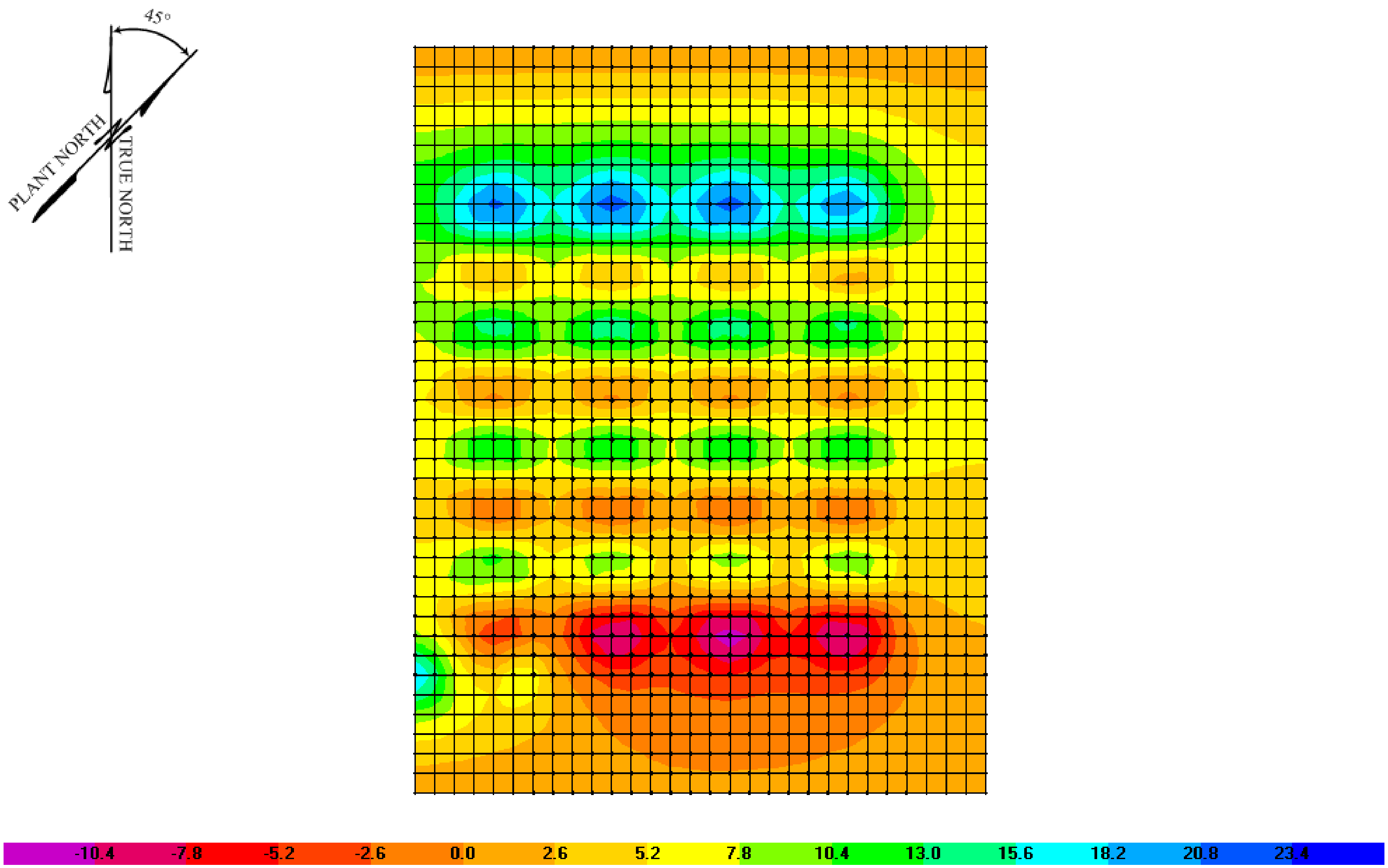
(MIN = -37.654 (k-ft), MAX = 29.386 (k-ft))

3 ft. Thick Resultant M12 Diagram - Combination 11 (DL_Edge+1(HX+HX_Edge)+0.4(HY+HY_Edge)-0.4(VZ+VZ_Edge))



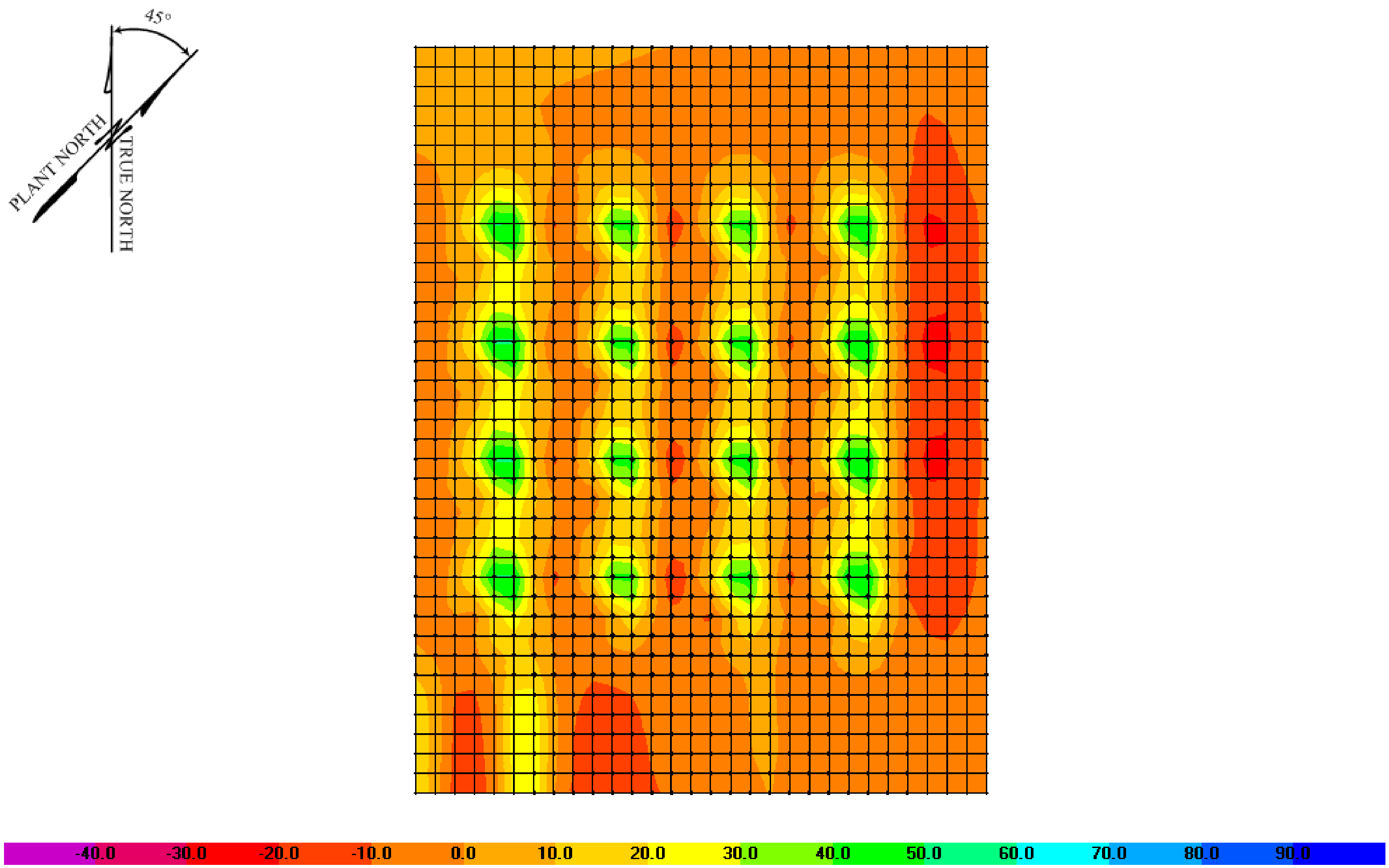
(MAX = 29.096 (kips))

3 ft. Thick Resultant V13 Diagram - Combination 11 (DL_Edge+1(HX+HX_Edge)+0.4(HY+HY_Edge)-0.4(VZ+VZ_Edge))



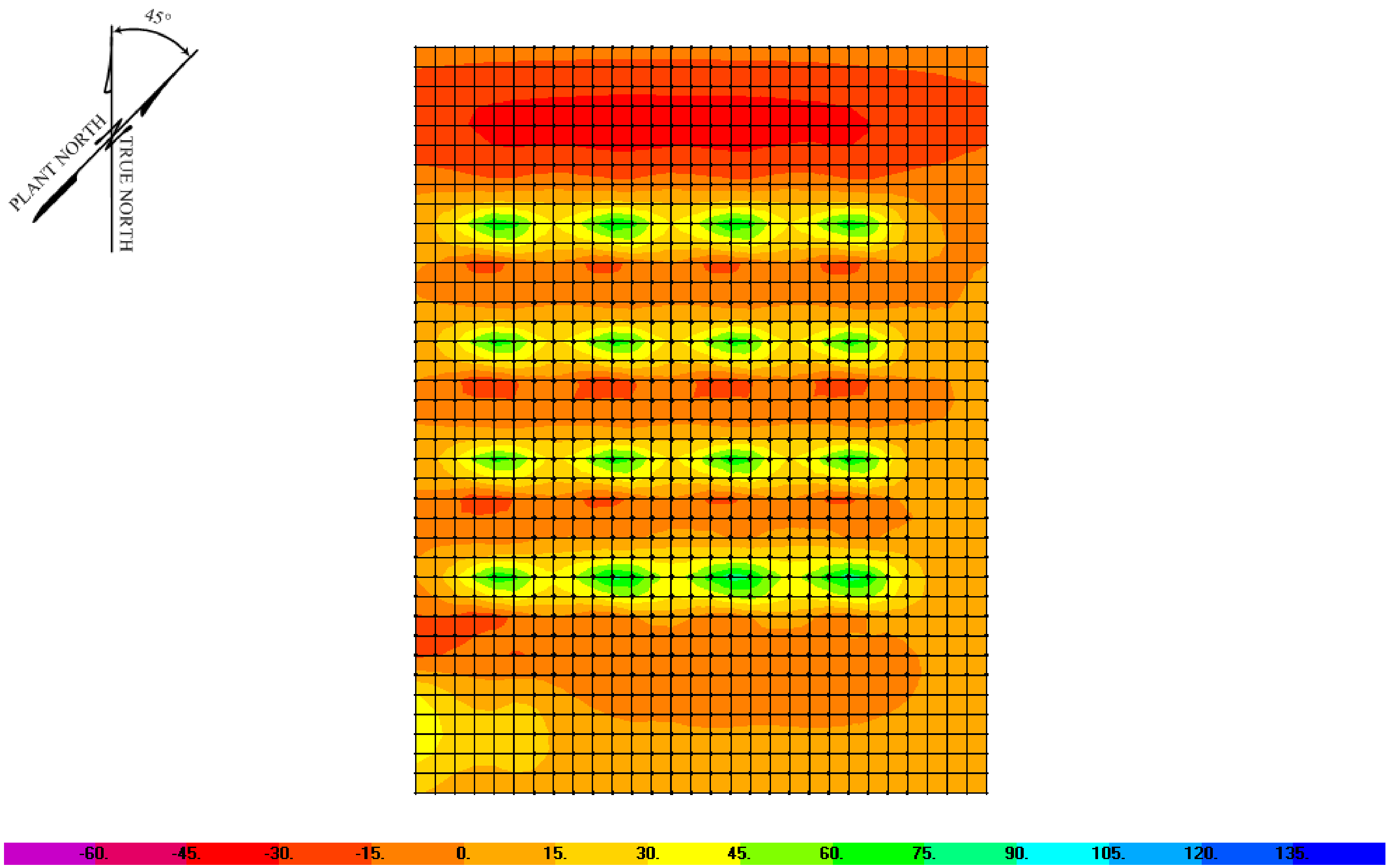
(MAX = 22.634 (kips))

3 ft. Thick Resultant V23 Diagram - Combination 11 (DL_Edge+1(HX+HX_Edge)+0.4(HY+HY_Edge)-0.4(VZ+VZ_Edge))



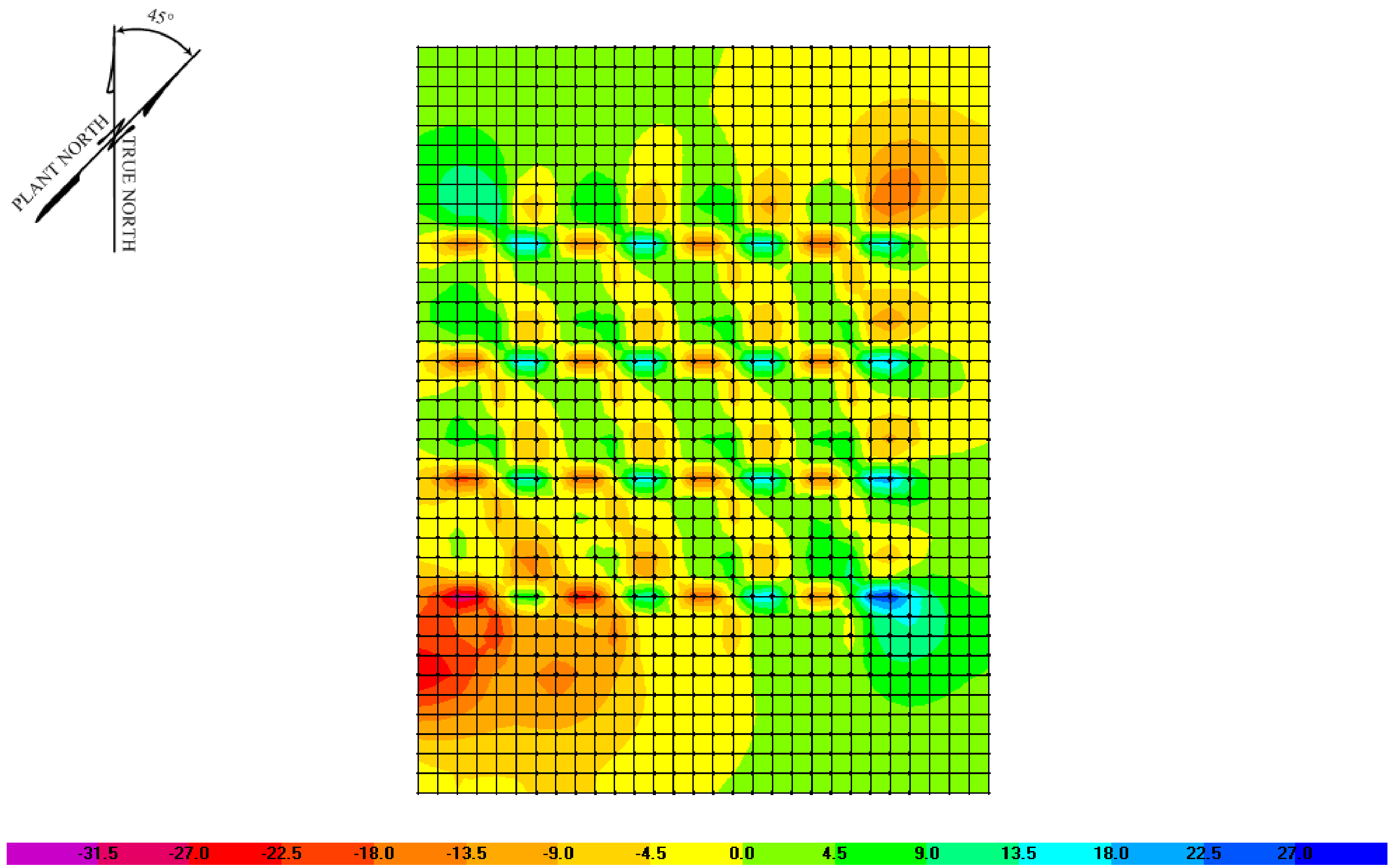
(MIN = -41.729 (k-ft), MAX = 90.052 (k-ft))

3 ft. Thick Resultant M11 Diagram - Combination 12 (DL_Edge+0.4(HX+HX_Edge)+1(HY+HY_Edge)-0.4(VZ+VZ_Edge))



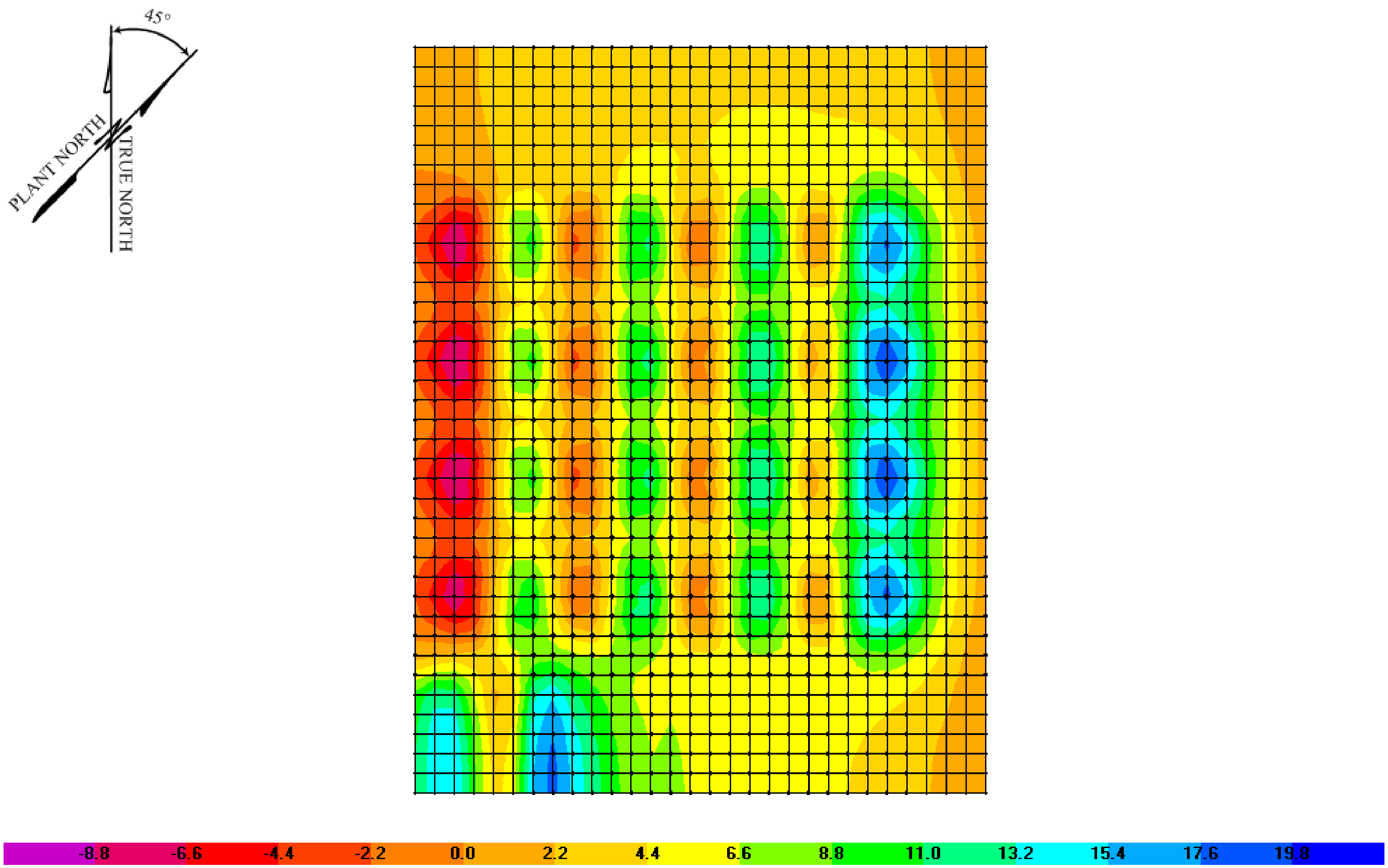
(MIN = -72.447 (k-ft), MAX = 138.905 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 12 (DL_Edge+0.4(HX+HX_Edge)+1(HY+HY_Edge)-0.4(VZ+VZ_Edge))



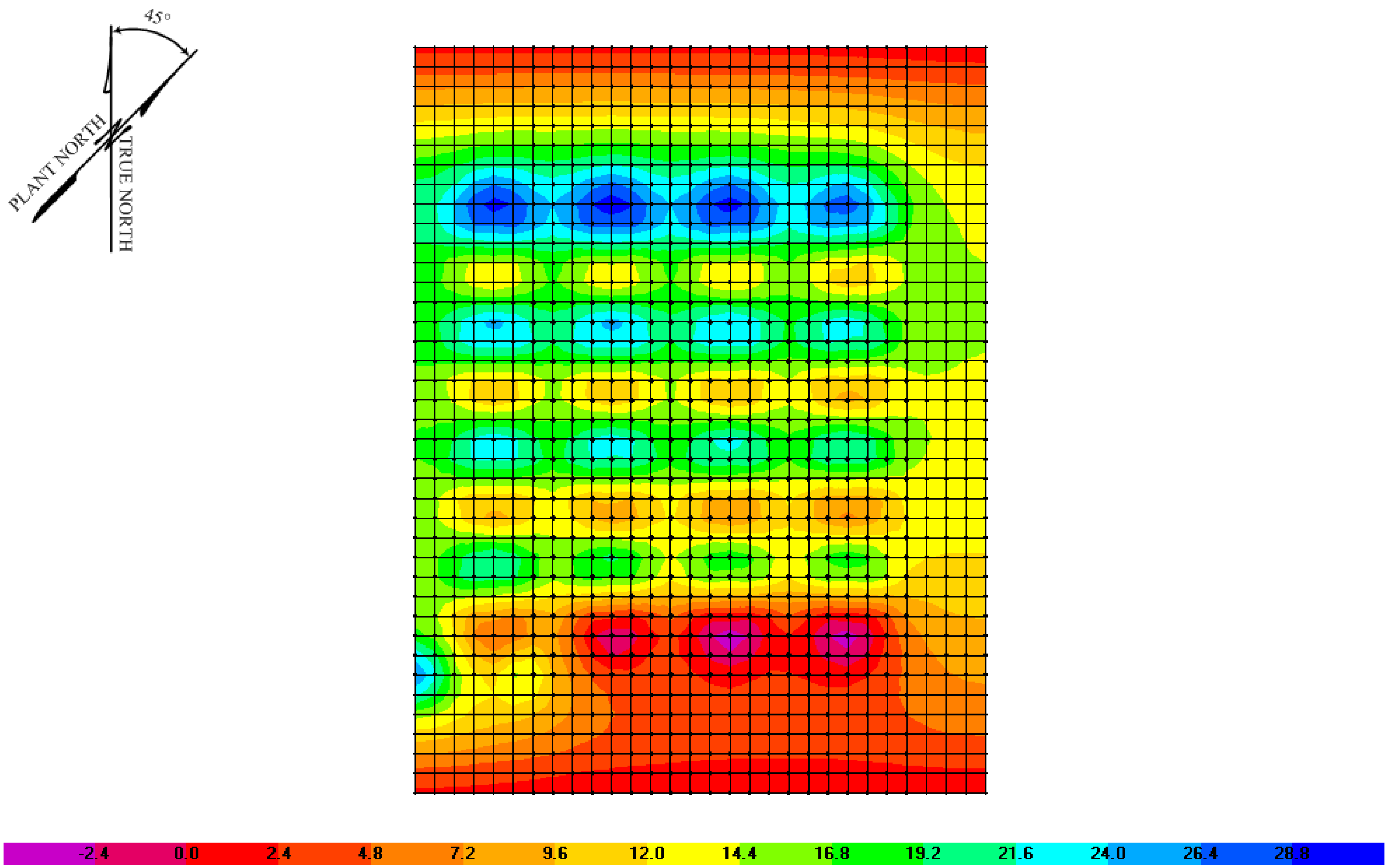
(MIN = -34.654 (k-ft), MAX = 29.735 (k-ft))

3 ft. Thick Resultant M12 Diagram - Combination 12 (DL_Edge+0.4(HX+HX_Edge)+1(HY+HY_Edge)-0.4(VZ+VZ_Edge))



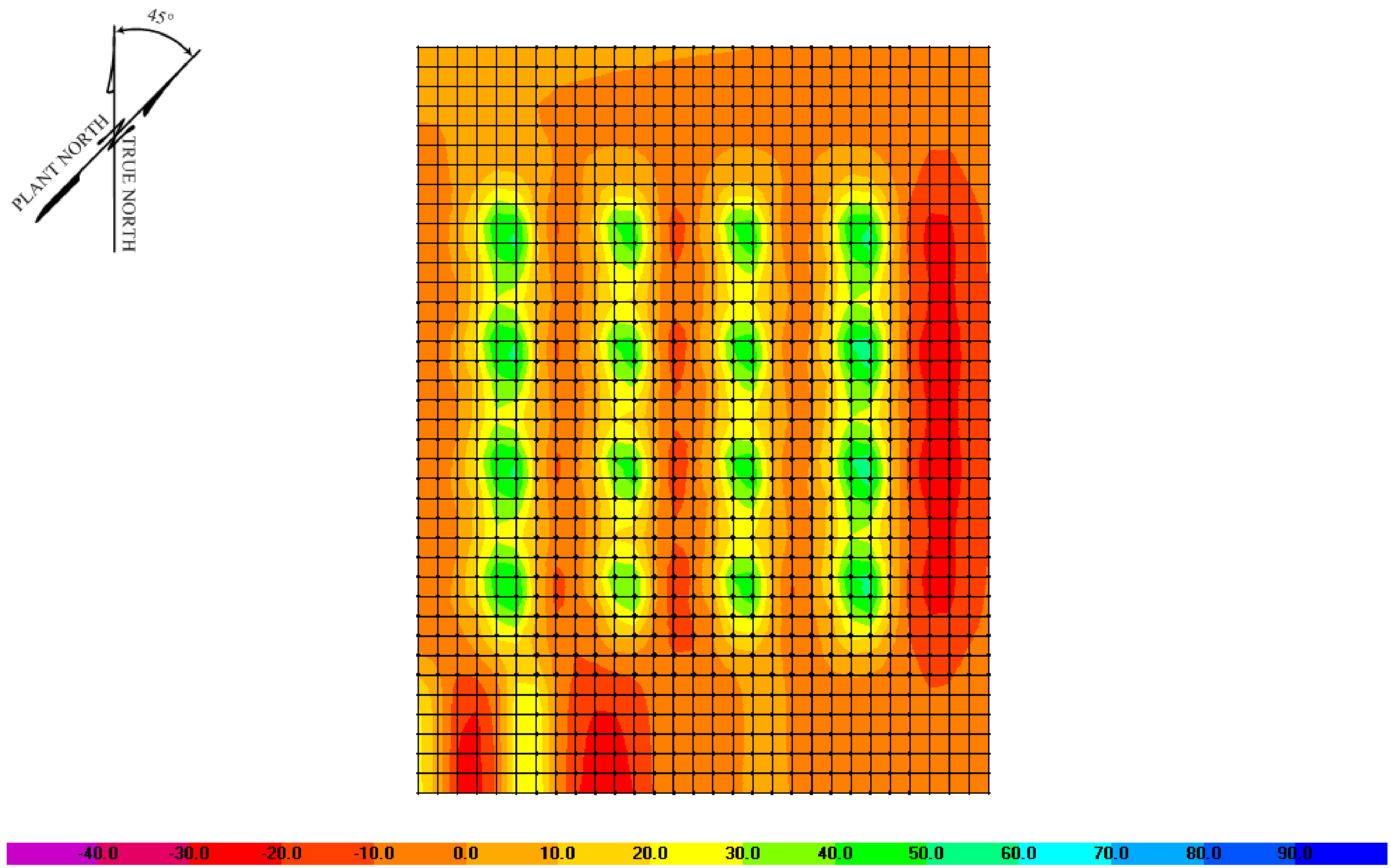
(MAX = 20.289 (kips))

3 ft. Thick Resultant V13 Diagram - Combination 12 (DL_Edge+0.4(HX+HX_Edge)+1(HY+HY_Edge)-0.4(VZ+VZ_Edge))



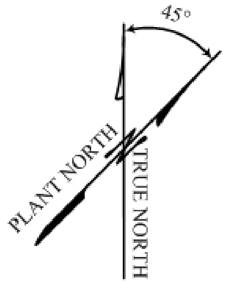
(MAX = 30.780 (kips))

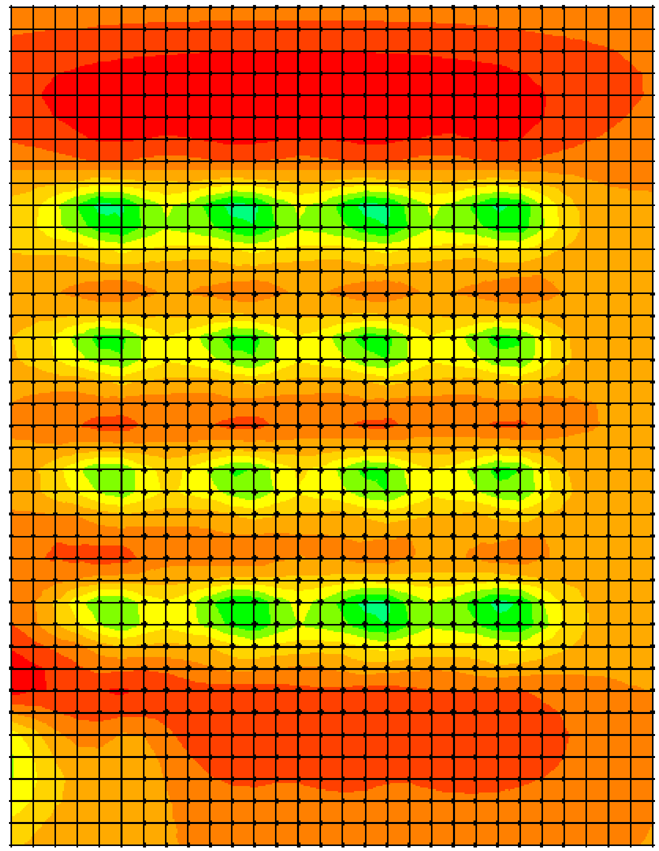
3 ft. Thick Resultant V23 Diagram - Combination 12 (DL_Edge+0.4(HX+HX_Edge)+1(HY+HY_Edge)-0.4(VZ+VZ_Edge))



(MIN = -44.376 (k-ft), MAX = 95.968 (k-ft))

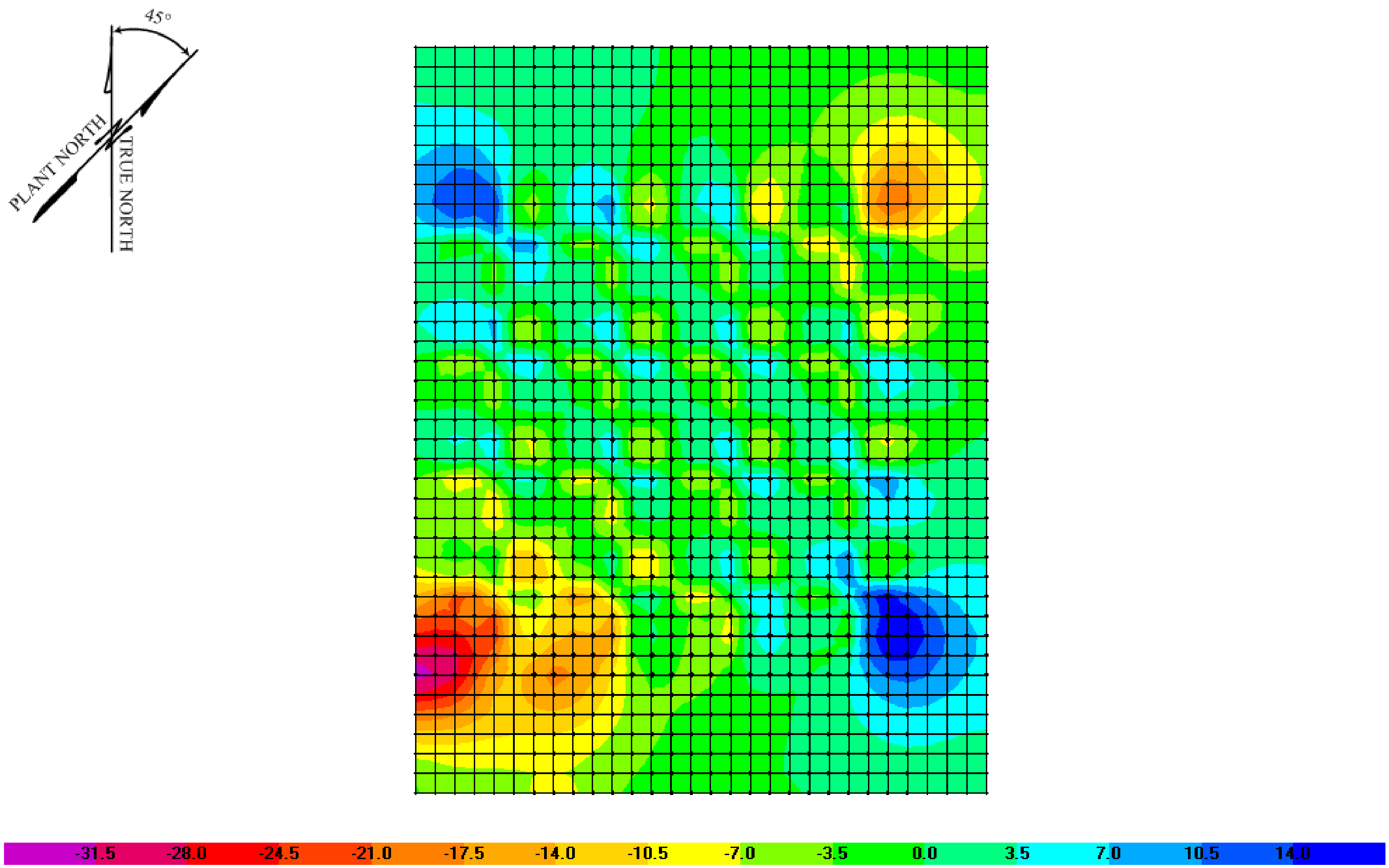
3 ft. Thick Resultant M11 Diagram - Combination 13 (DL_Edge+0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))





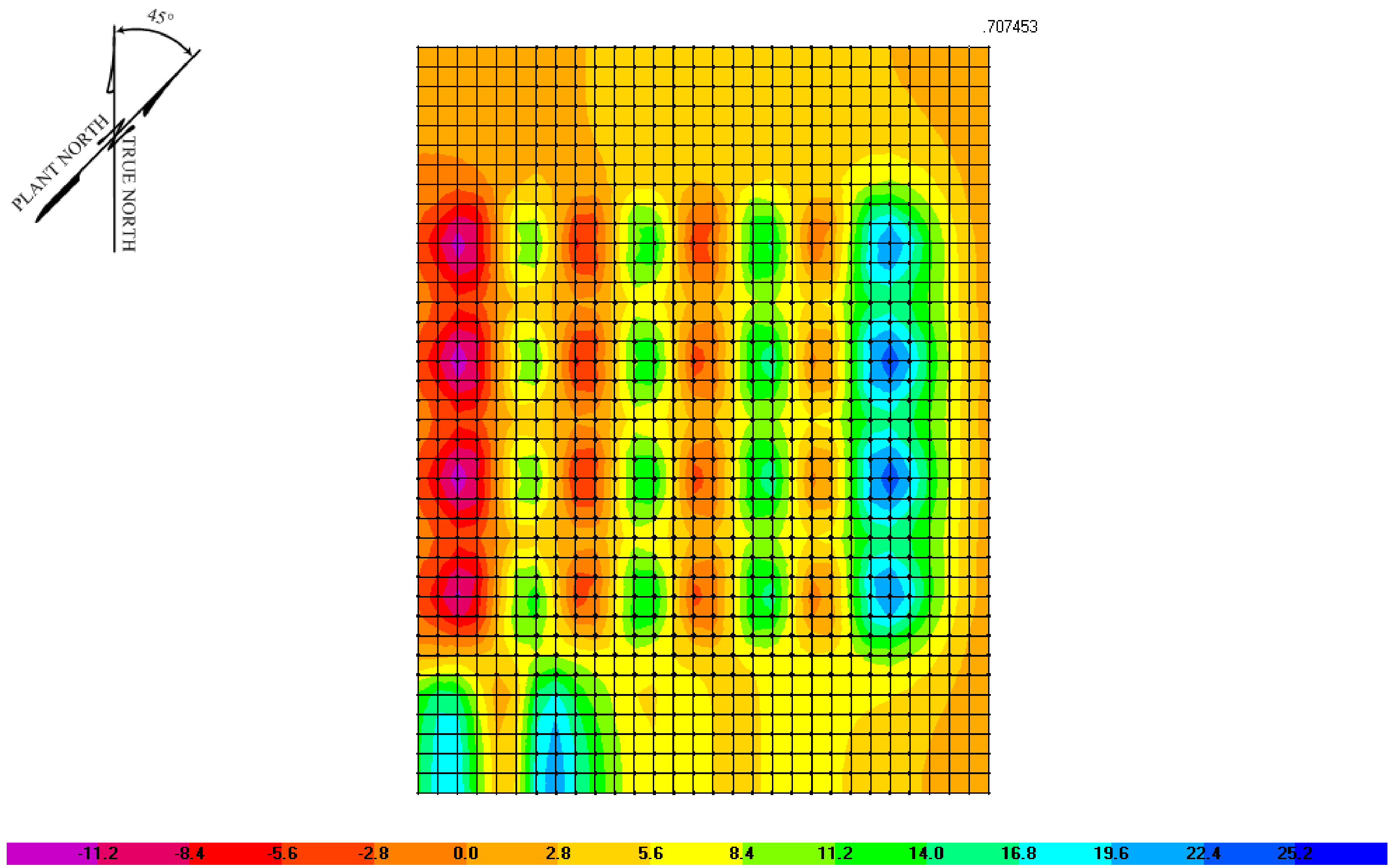
(MIN = -49.655 (k-ft), MAX = 103.227 (k-ft))

3 ft. Thick Resultant M22 Diagram - Combination 13 (DL_Edge+0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



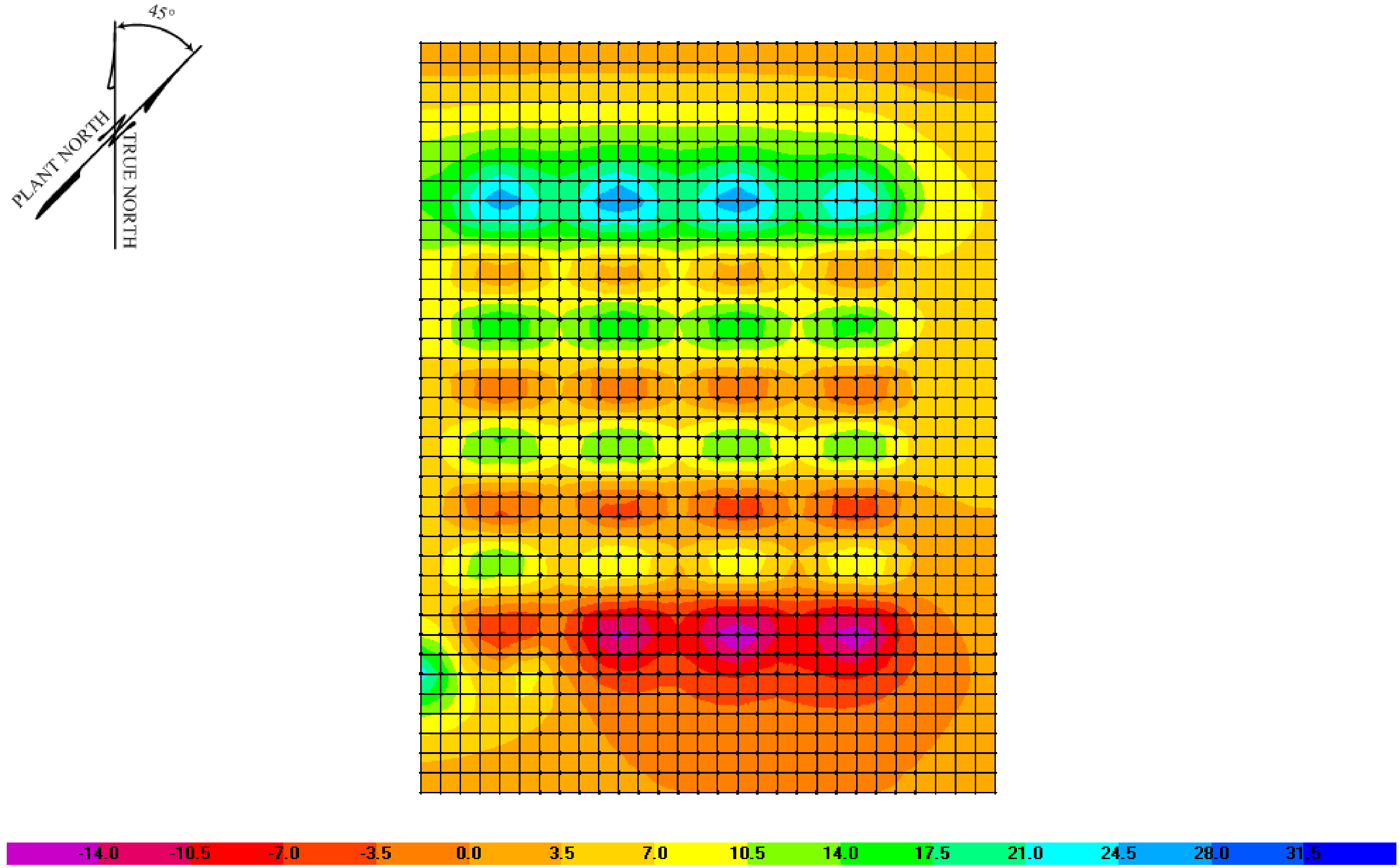
(MIN = -33.043 (k-ft), MAX = 17.473 (k-ft))

3.ft. Thick Resultant M12 Diagram - Combination 13 (DL_Edge+0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



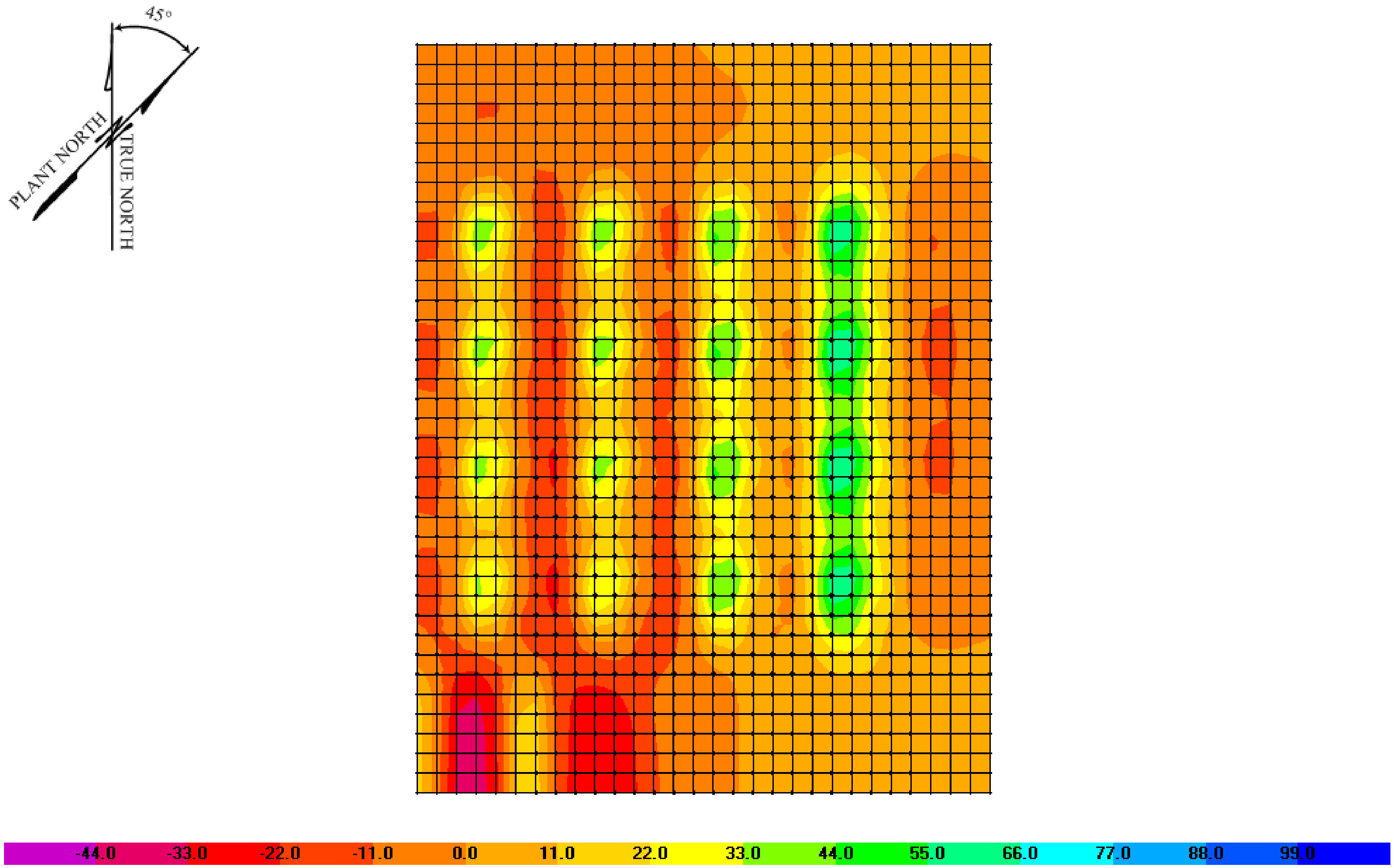
(MAX = 24.539 (kips))

3ft. Thick Resultant V13 Diagram - Combination 13 (DL_Edge+0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



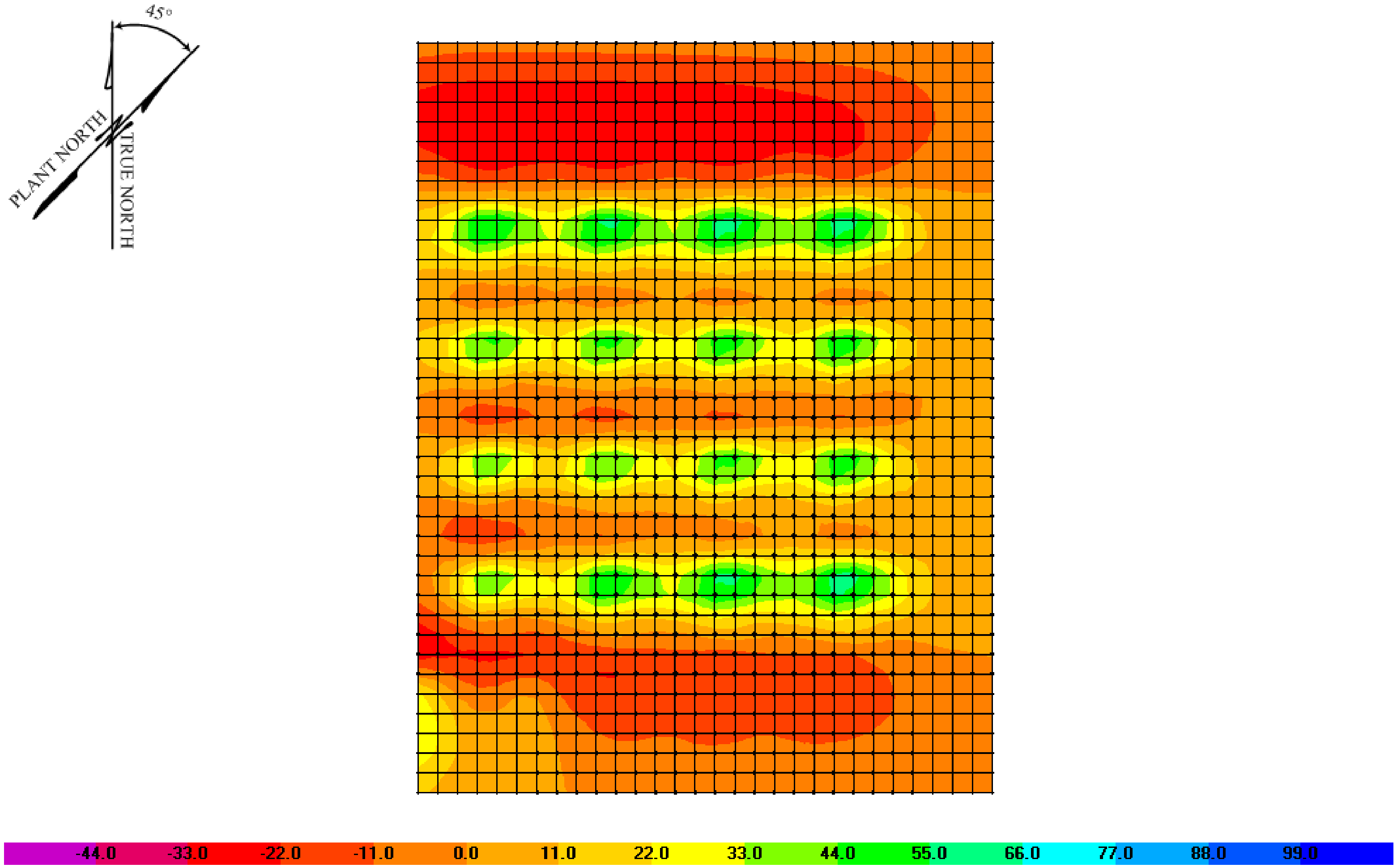
(MAX = 27.908 (kips))

3.ft. Thick Resultant V23 Diagram - Combination 13 (DL_Edge+0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



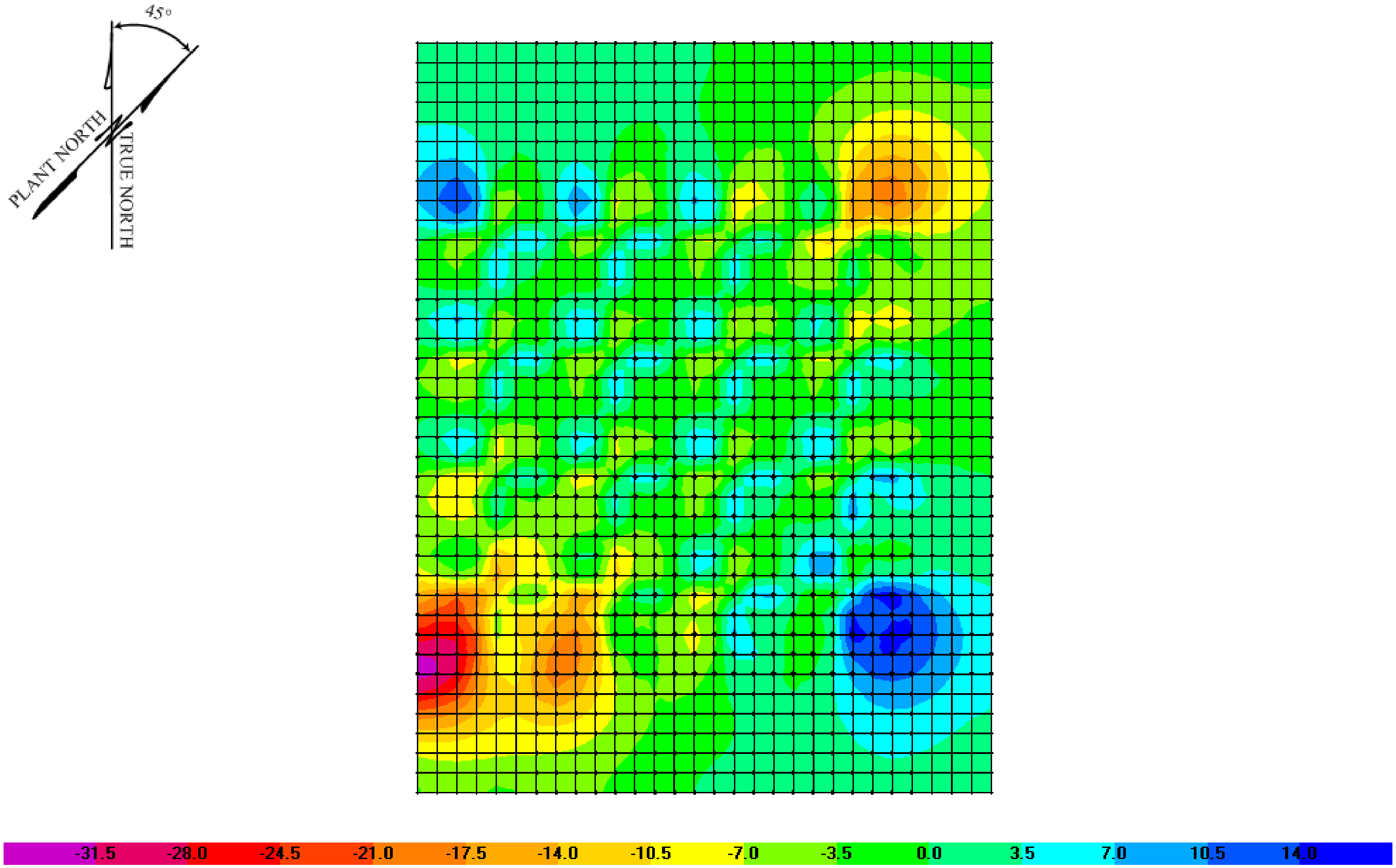
(MIN = -50.575 (k-ft), MAX = 92.259 (k-ft))

3ft. Thick Resultant M11 Diagram - Combination 14 (DL_Edge -0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



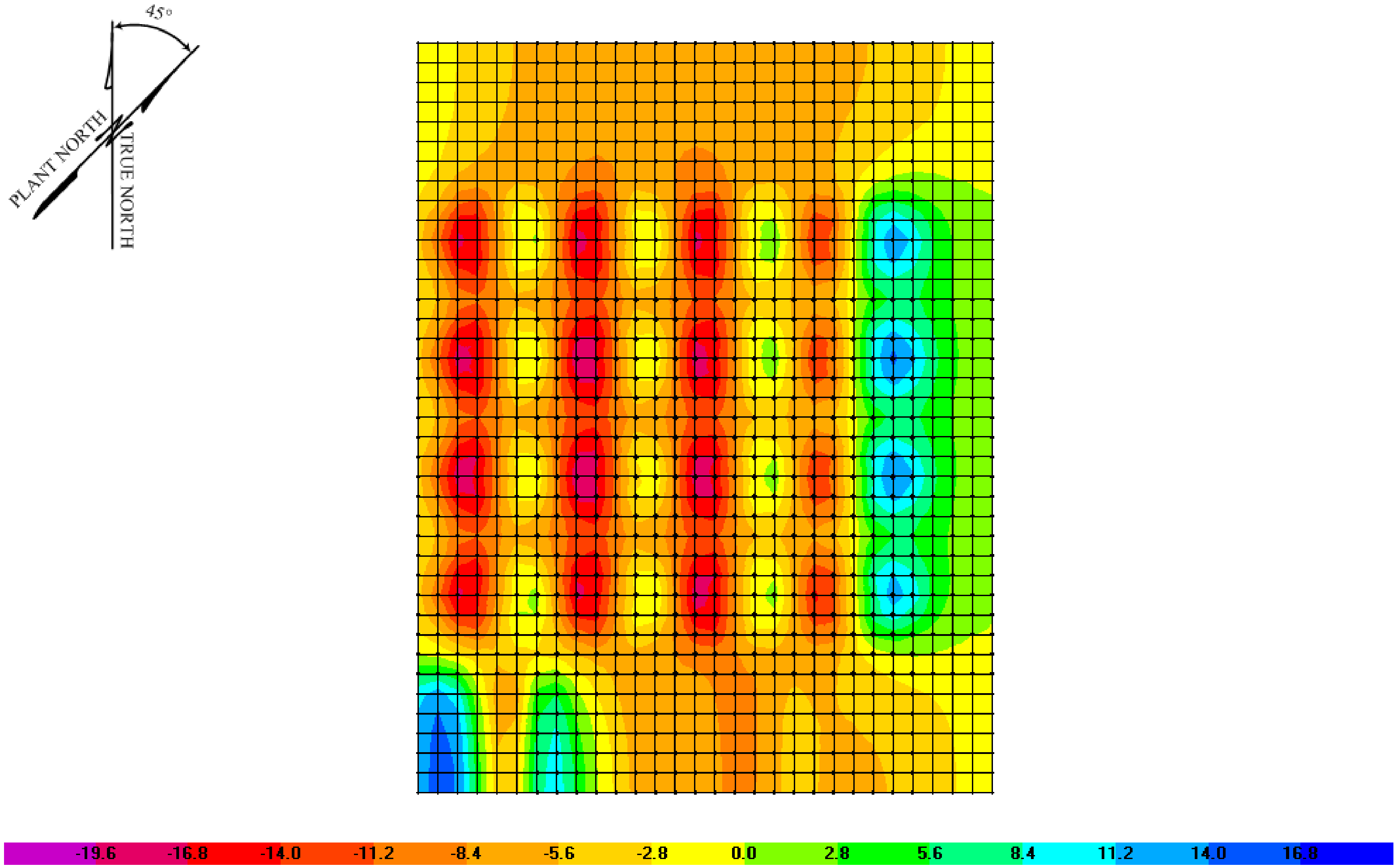
(MIN = -52.571 (k-ft), MAX = 104.207 (k-ft))

3ft. Thick Resultant M22 Diagram - Combination 14 (DL_Edge -0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



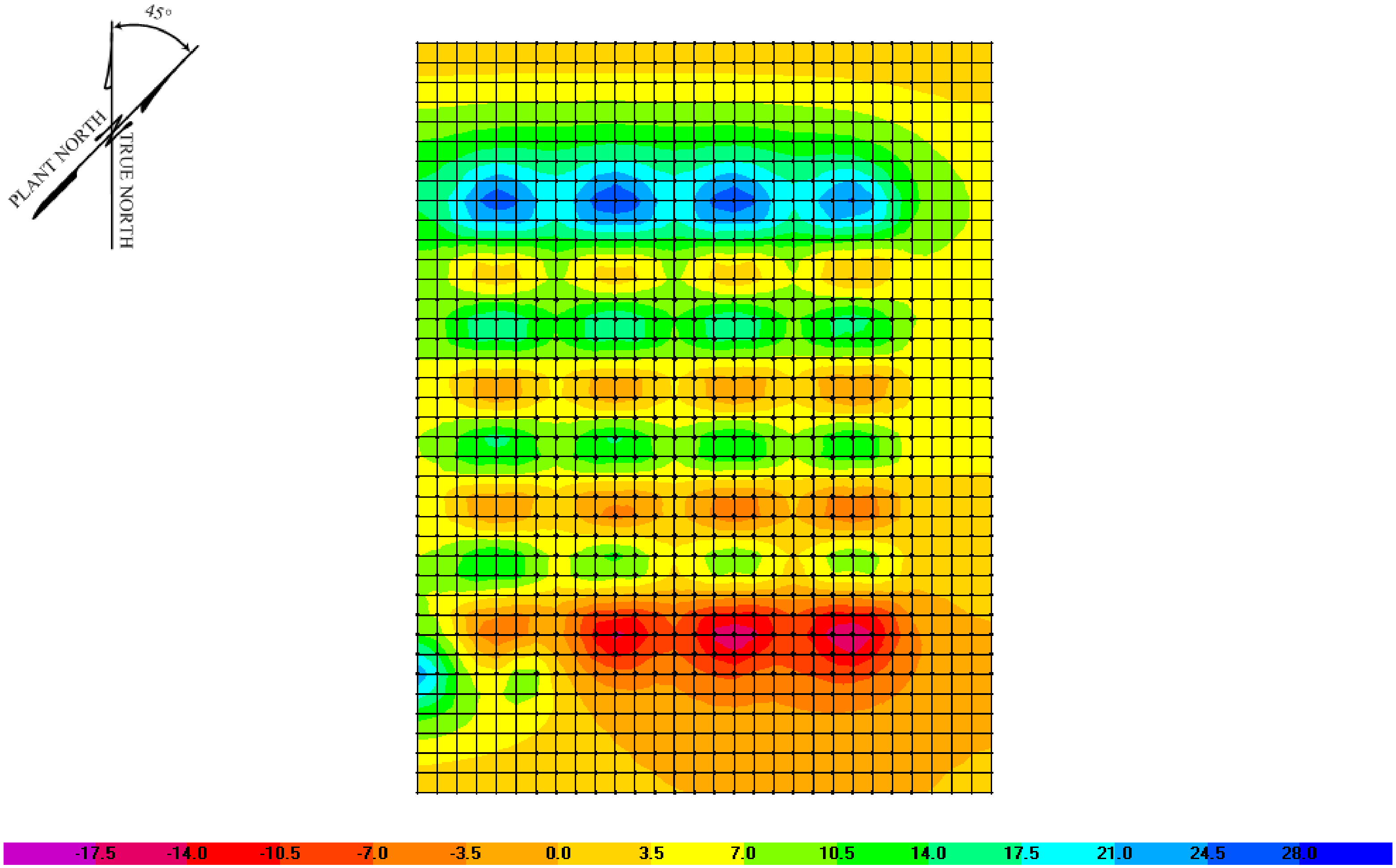
(MIN = -33.536 (k-ft), MAX = 17.480 (k-ft))

3ft. Thick Resultant M12 Diagram - Combination 14 (DL_Edge -0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



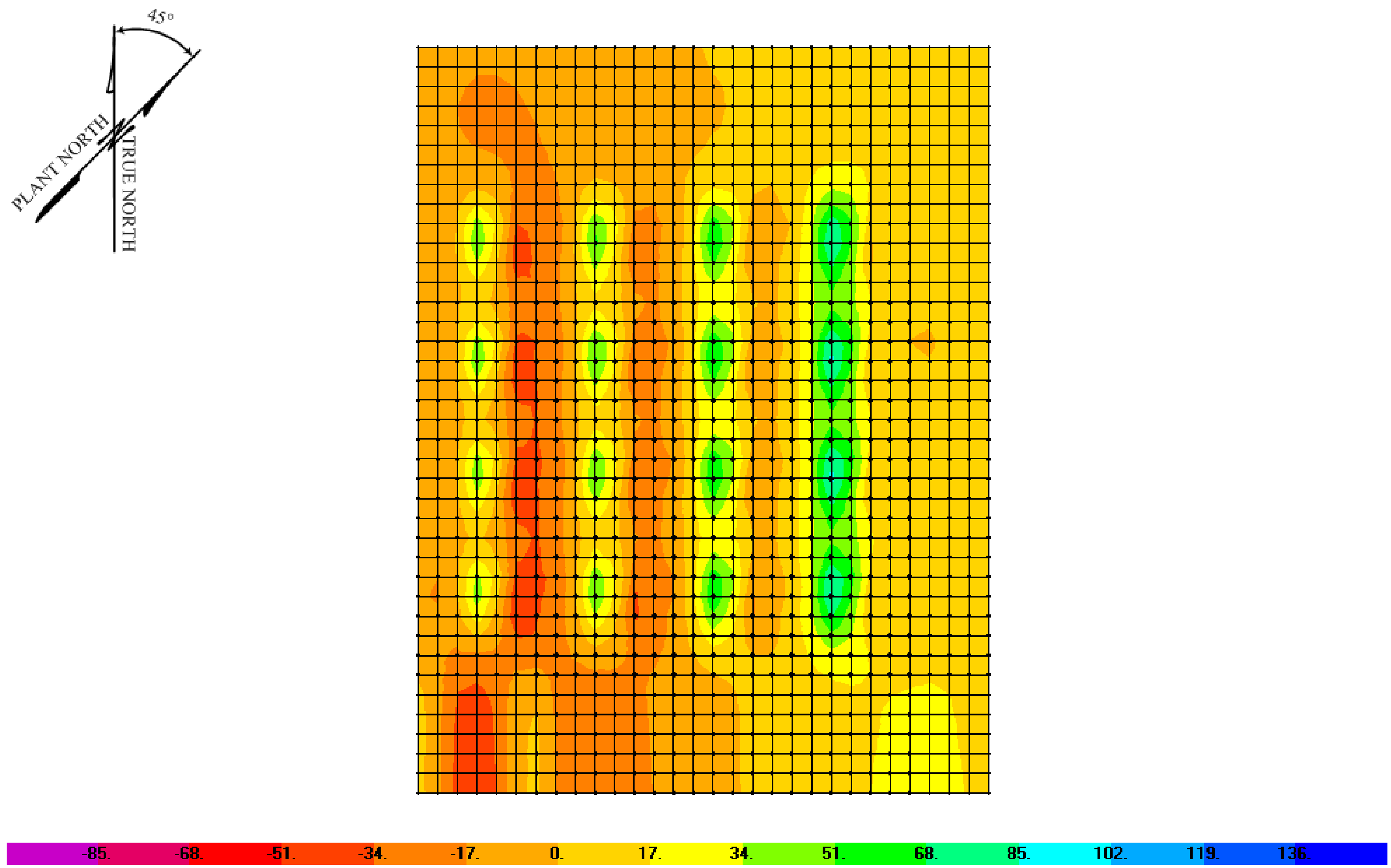
(MAX = 20.990 (kips))

3ft. Thick Resultant V13 Diagram - Combination 14 (DL_Edge -0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



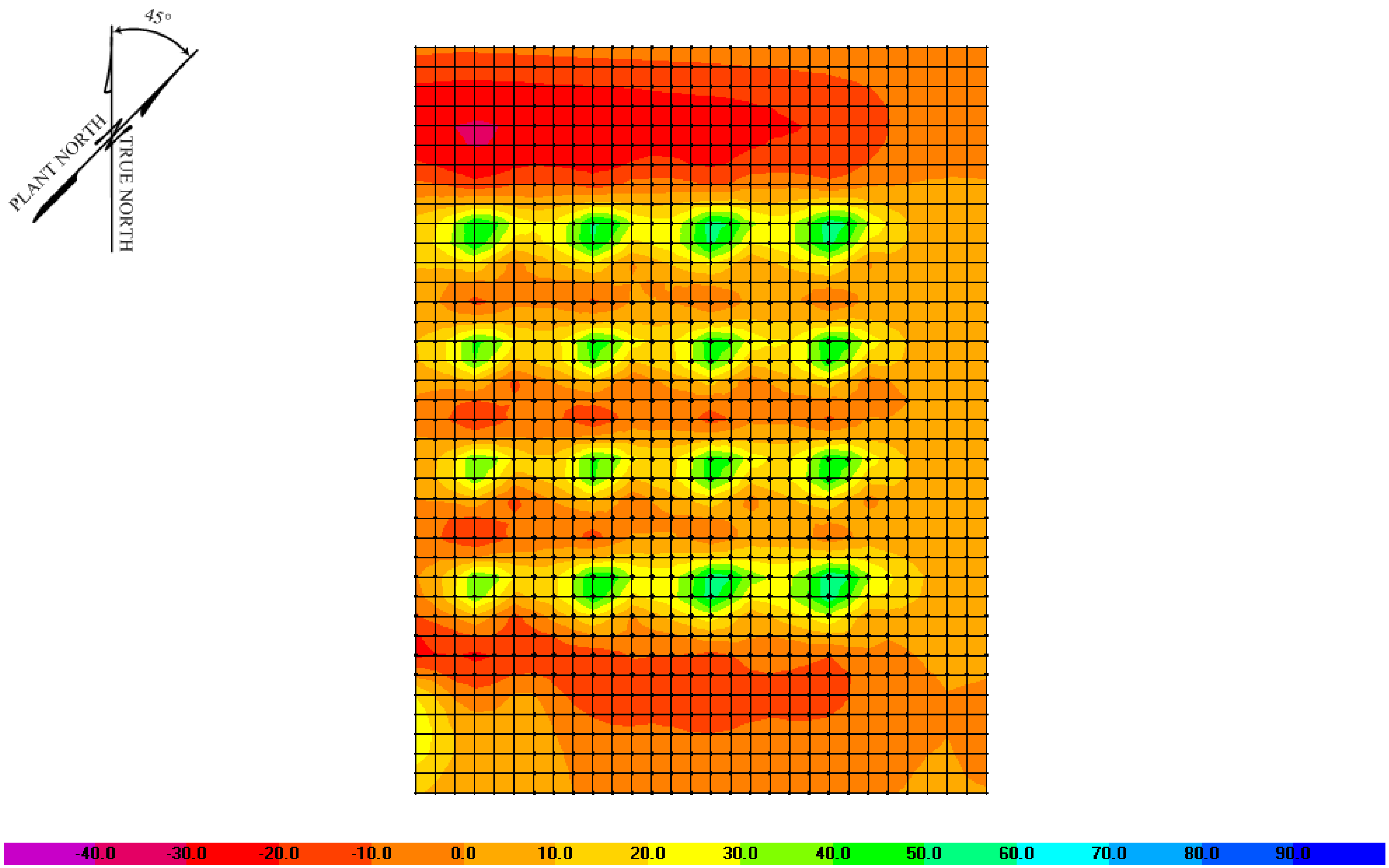
(MAX = 28.035 (kips))

3ft. Thick Resultant V23 Diagram - Combination 14(DL_Edge -0.4(HX+HX_Edge)+ 0.4 (HY+HY_Edge) -1 (VZ+VZ_Edge))



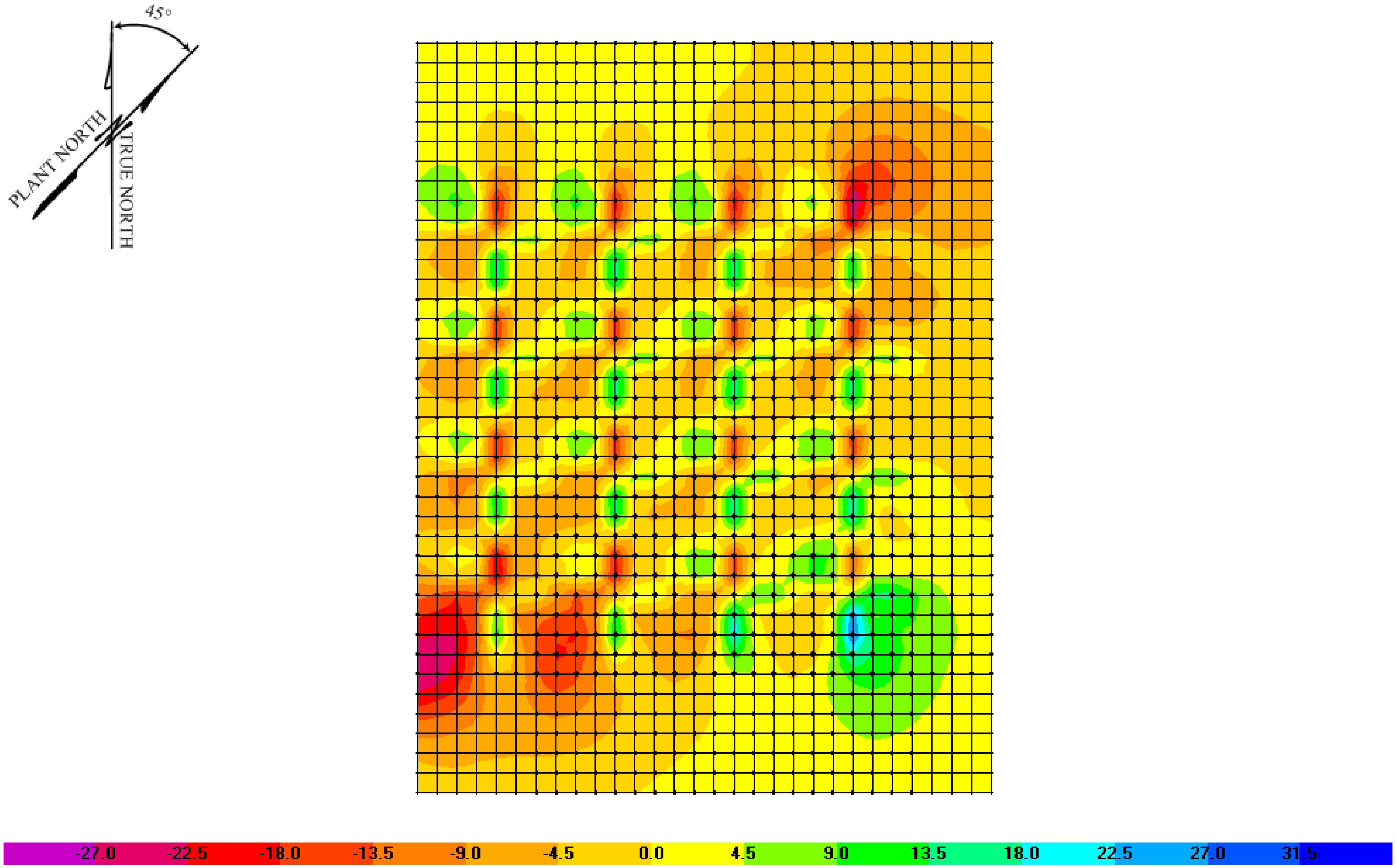
(MIN = -93.448 (k-ft), MAX = 144.363 (k-ft))

3ft. Thick Resultant M11 Diagram - Combination 15 (DL_Edge -1(HX+HX_Edge)+ 0.4 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



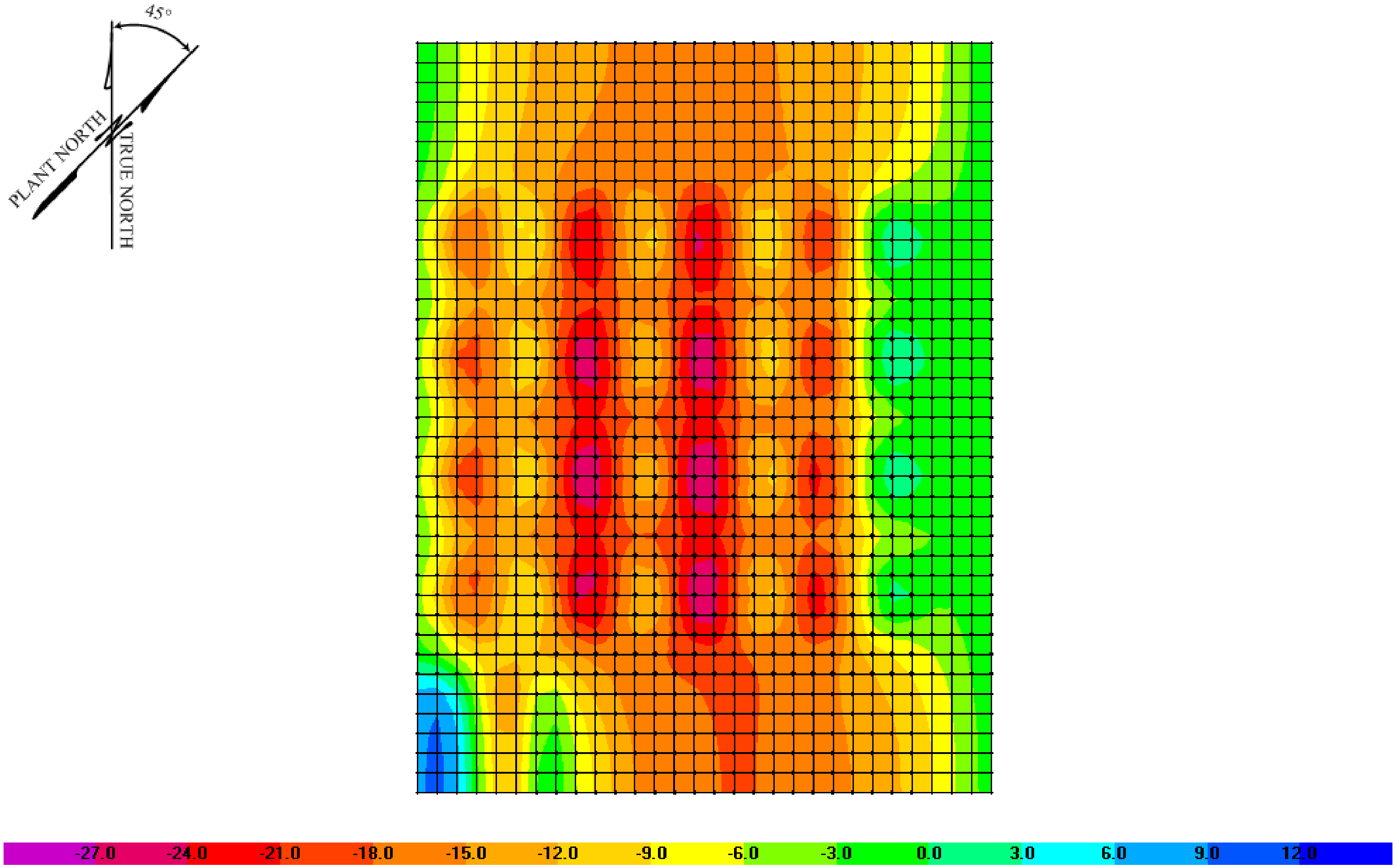
(MIN = -48.235 (k-ft), MAX = 97.359 (k-ft))

3ft. Thick Resultant M22 Diagram - Combination 15 (DL_Edge -1(HX+HX_Edge)+ 0.4 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



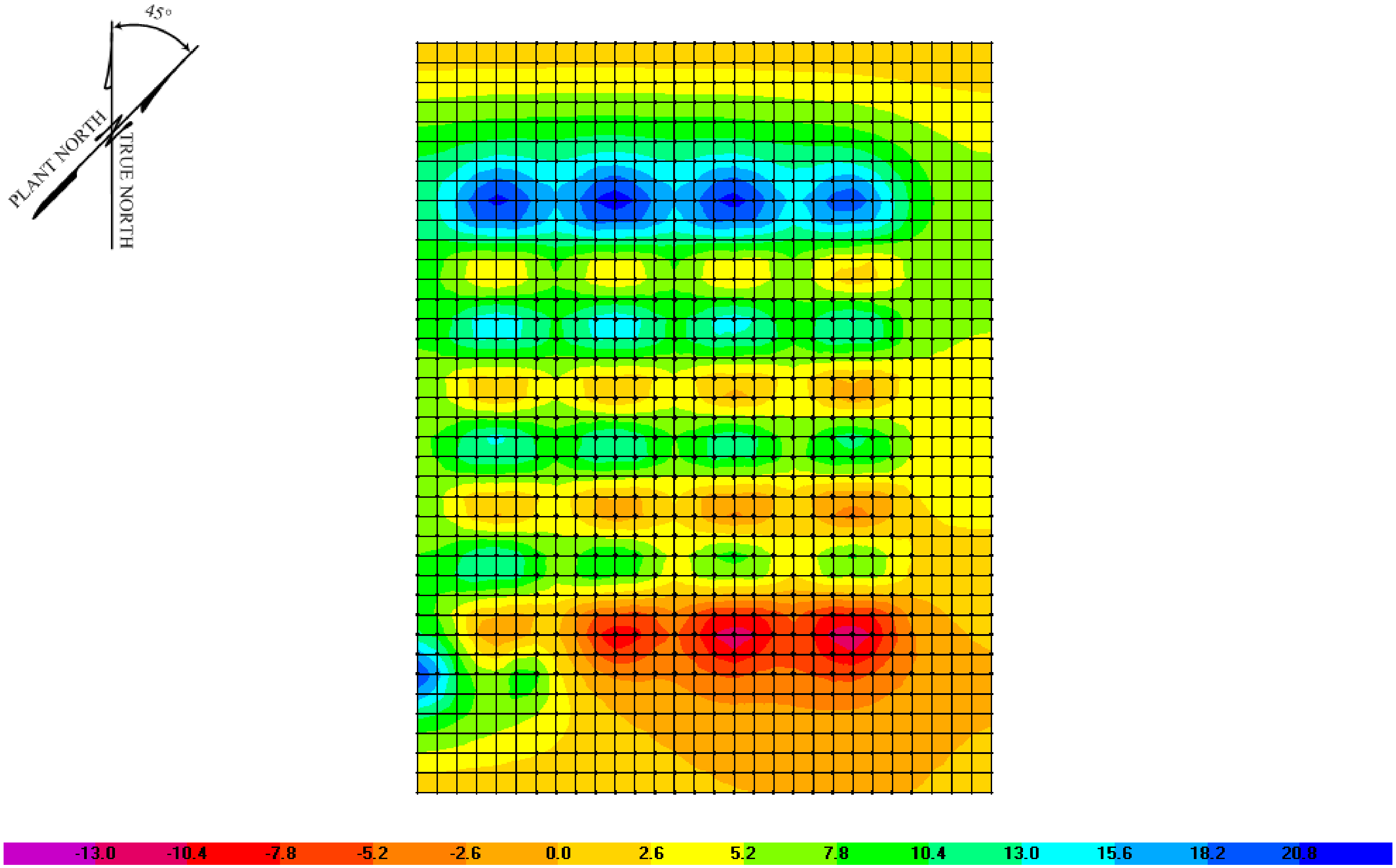
(MIN = -31.395 (k-ft), MAX = 30.346 (k-ft))

3ft. Thick Resultant M12 Diagram - Combination 15 (DL_Edge -1(HX+HX_Edge)+ 0.4 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



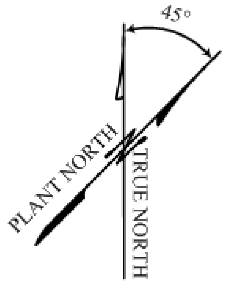
(MAX = 28.236 (kips))

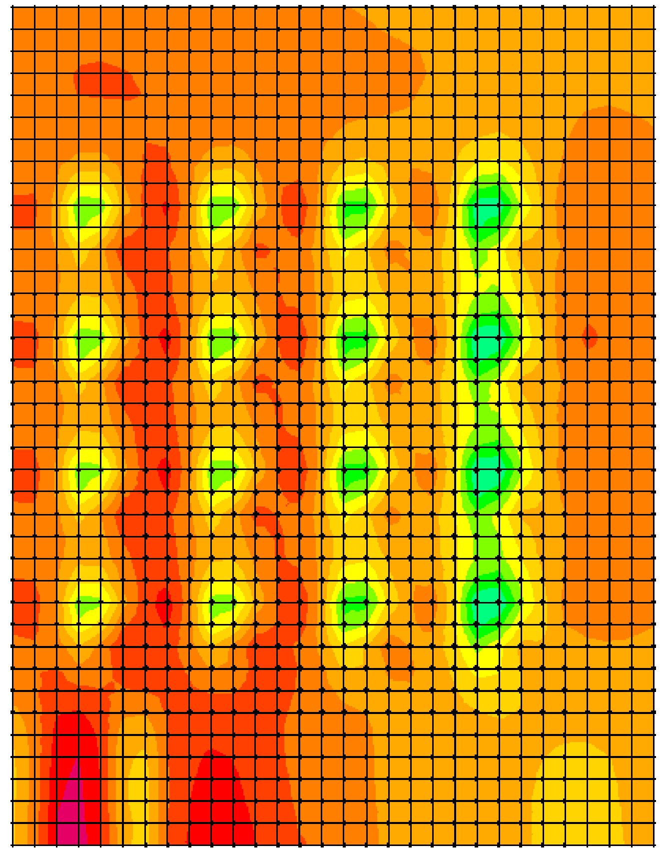
3ft. Thick Resultant V13 Diagram - Combination 15 (DL_Edge -1(HX+HX_Edge)+ 0.4 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



(MAX = 22.892 (kips))

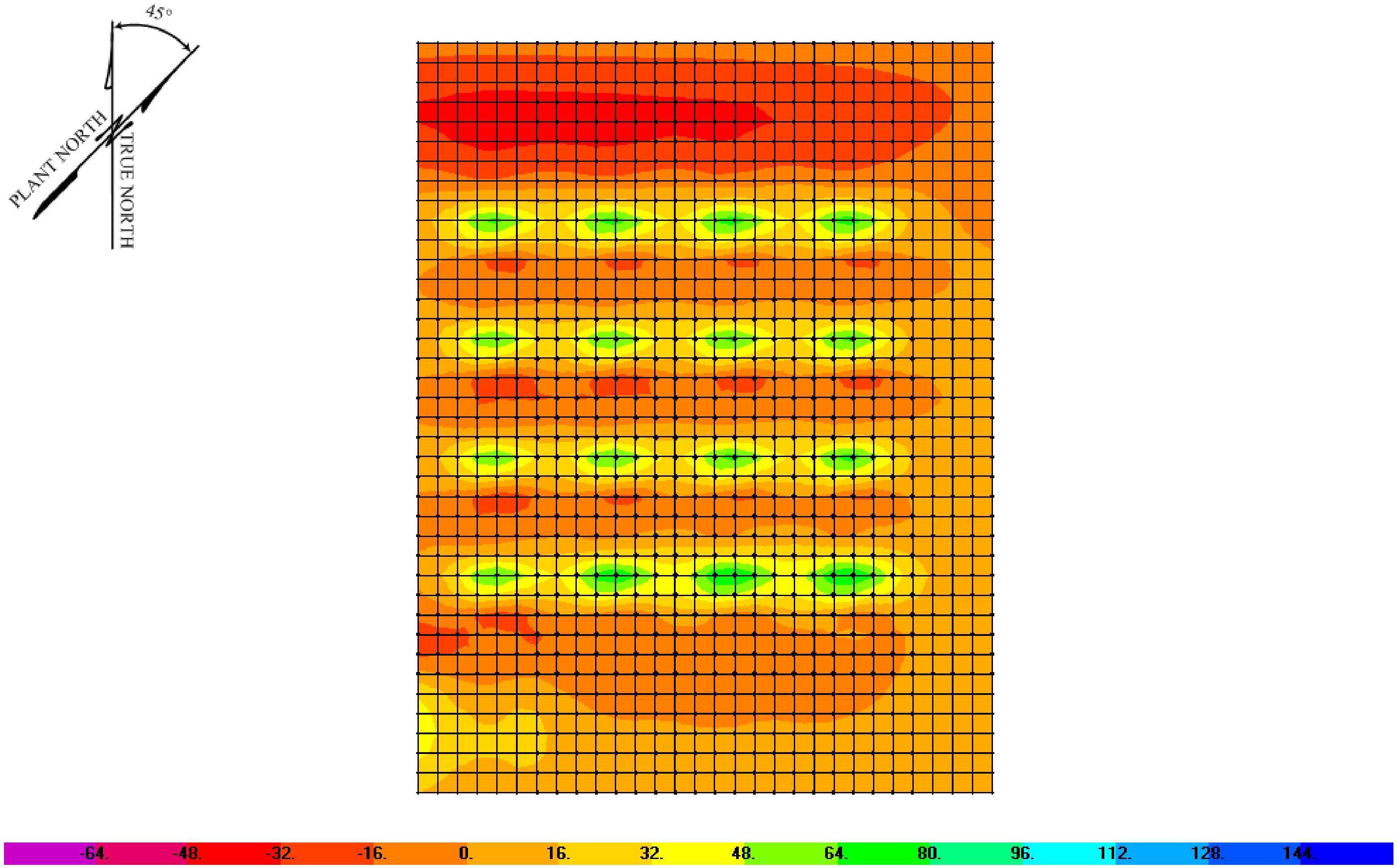
3ft. Thick Resultant V23 Diagram - Combination 15 (DL_Edge -1(HX+HX_Edge)+ 0.4 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))





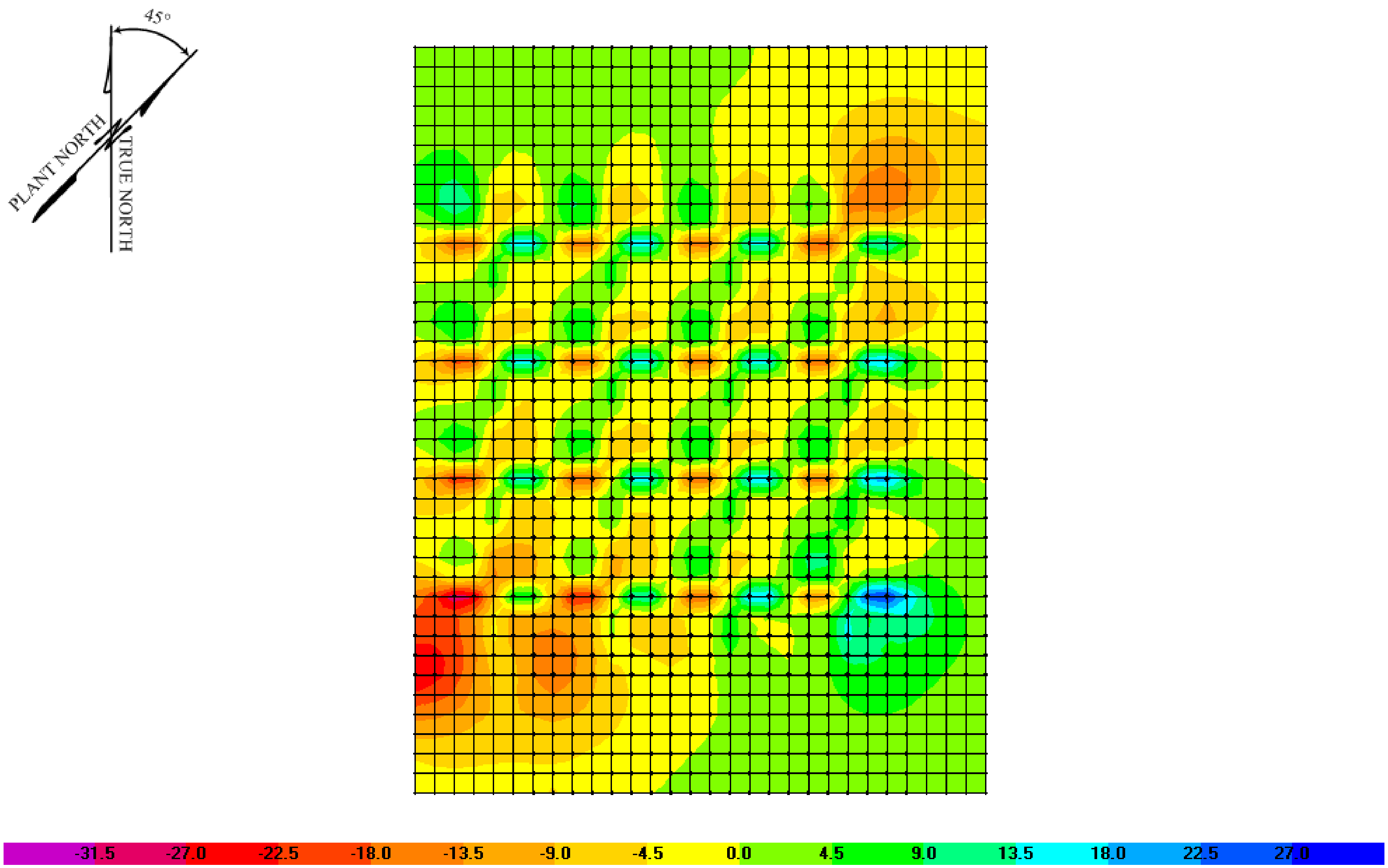
(MIN = -41.365 (k-ft), MAX = 90.621 (k-ft))

3ft. Thick Resultant M11 Diagram - Combination 16 (DL_Edge –0.4(HX+HX_Edge)+ 1 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



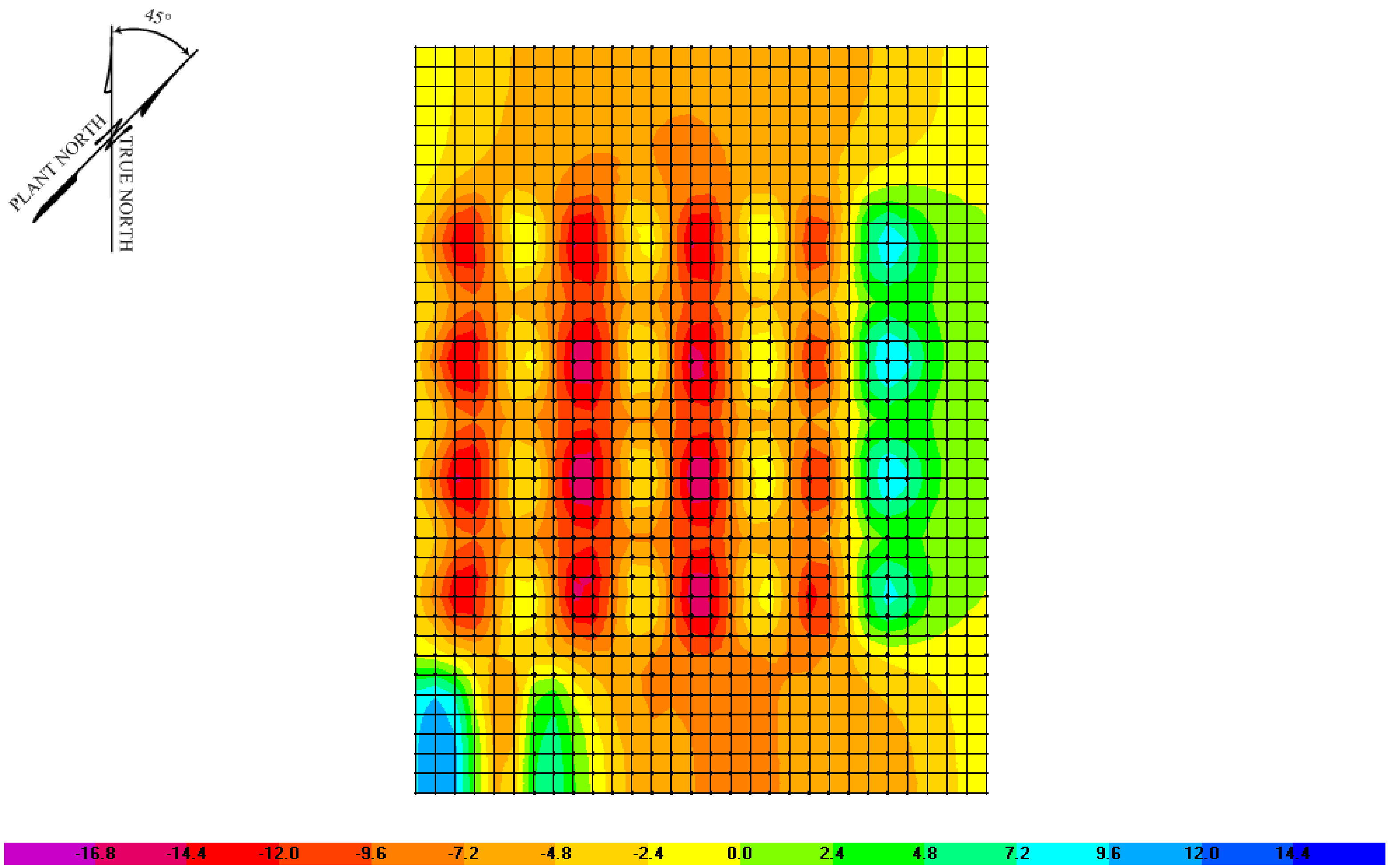
(MIN = -76.433 (k-ft), MAX = 139.101 (k-ft))

3ft. Thick Resultant M22 Diagram - Combination 16 (DL_Edge –0.4(HX+HX_Edge)+ 1 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



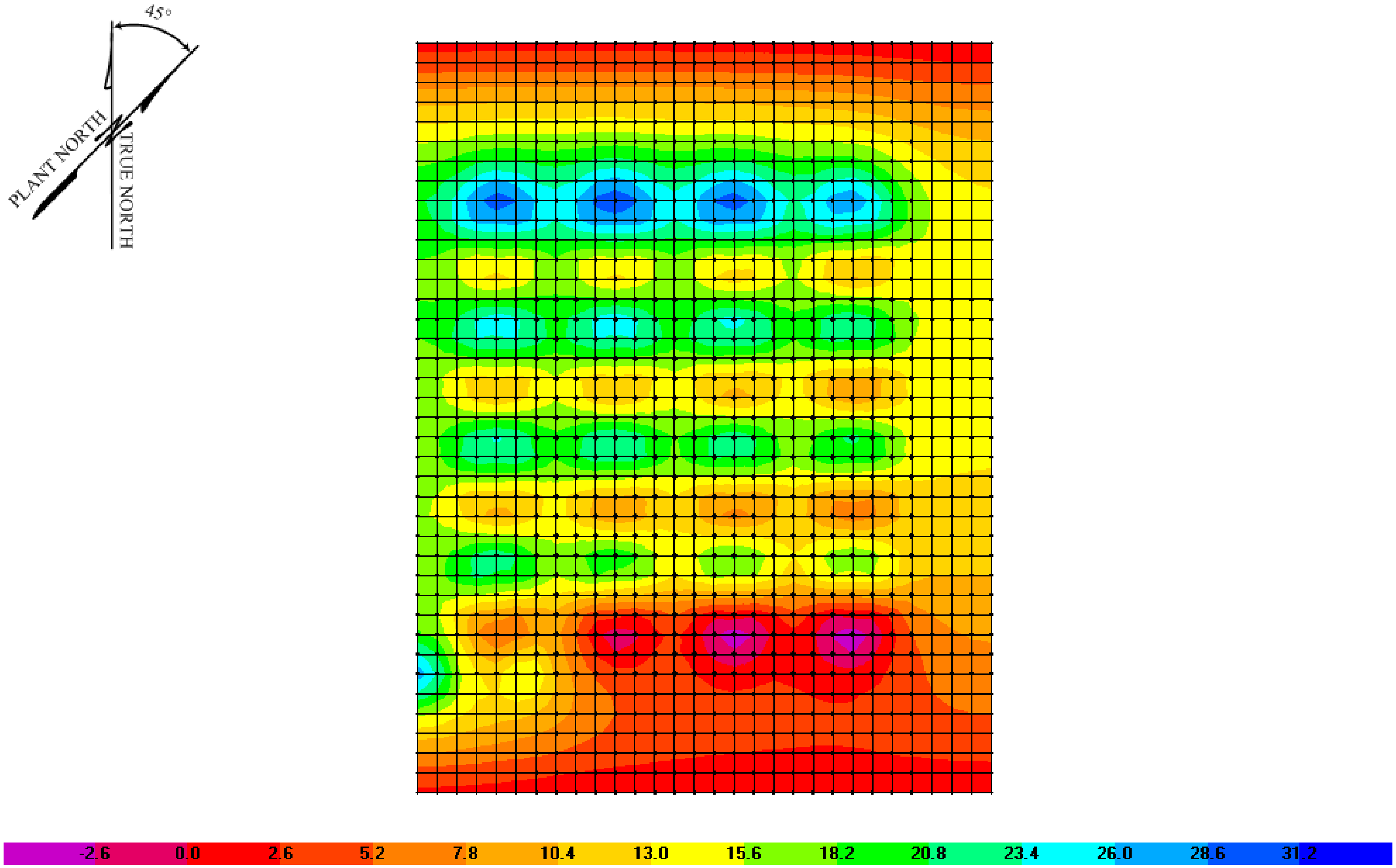
(MIN = -34.050 (k-ft), MAX = 30.053 (k-ft))

3ft. Thick Resultant M12 Diagram - Combination 16 (DL_Edge –0.4(HX+HX_Edge)+ 1 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



(MAX = 17.976 (kips))

3ft. Thick Resultant V13 Diagram - Combination 16 (DL_Edge –0.4(HX+HX_Edge)+ 1 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))



(MAX = 30.924 (kips))

3ft. Thick Resultant V23 Diagram - Combination 16 (DL_Edge –0.4(HX+HX_Edge)+ 1 (HY+HY_Edge) –0.4 (VZ+VZ_Edge))

ATTACHMENT D
AGING CASK STABILITY ANALYSIS (DBGM-2)
(Reference 2.2.25, Seismic Design Criteria for Structures, Systems, and Components in Nuclear Facilities)

h=H/2=11'	11	H = 22 ft., Height of Aging Overpack, Reference. 2.2.17
b=B/2=6'	6	B = 12 ft., Base diameter of Aging Overpack, Ref. 2.2.17
a=b/h=	0.545455	Reference. 2.2.25, Eq. 7-2(b)
α=arctan (a)=		
FH=1.0	1	Reference. 2.2.25, Eq. B-32(a)
$C_I=(4/3)(1+a^2)=$	1.73	Reference. 2.2.25, Eq. A-6(f)
$C_R=(1-2a^2/C_I)=$	0.656046	Reference. 2.2.25, Eq. A-6(e) & page 37 (For C_R = 0.656, say 0.7, β_e = 11.3%, **Use 10% damping**)

NEW R-S, DBGM-2 (10% Damping) (Equations used from Reference 2.2.25 and values in first row of Table below are verified below using Mathcad.

Θ, rad.	Θ, deg	$f_1(\Theta)$	$f_1(\Theta)$-1	f_e	$1/f_e$	AV, g	S_{AH}Dem, AH, 9	V	AHCap	D-C
0.0001	0.00573	1.000055	5.45E-05	21.622316	0.046249	0.579	0.661	1.108279	0.98424	-0.32324
0.0002	0.011459	1.000109	0.000109	15.288585	0.065408	0.608	0.785	1.0855S7	1.00473	-0.21973
0.0003	0.017189	1.000164	0.000164	12.482505	0.080112	0.617	0.852	1.075188	1.01434	-0.16234
0.0004	0.022918	1.000218	0.000218	10.809671	0.092510	0.622	0.891	1.070043	1.01913	-0.12813
0.0005	0.028648	1.000273	0.000273	9.668020	0.103434	0.616	0.907	1.066412	1.02250	-0.11550
0.0006	0.034377	1.000327	0.000327	8.825250	0.113311	0.595	0.900	1.063032	1.02566	-0.12566
0.0010	0.057296	1.000545	0.000545	6.834755	0.146311	0.533	0.877	1.053515	1.03455	-0.15755

Conclusion: Under DBGM-2, the demand never reaches the capacity at 10% damping; therefore, the cask does not lift up.
Use 7% damping spectra for DBGM-2 to assess stability angle for rocking
NEW R-S, DBGM-2 (7% Damping, used for higher values of S_{AV} and S_{AH} in section 6.3.2)

Θ, rad.	Θ, deg	$f_1(\Theta)$	$f_1(\Theta)$-1	f_e	$1/f_e$		S_{AH}Dem,	V	AHCap	D-C
0.0001	0.00573	1.000055	5.45E-05	21.622316	0.046249	0.647	0.725	1.112181	0.98078	-0.25578
0.0002	0.011459	1.000109	0.000109	15.288585	0.065408	0.690	0.876	1.088388	1.00213	-0.12613
0.0003	0.017189	1.000164	0.000164	12.482505	0.080112	0.704	0.956	1.0S7656	1.01202	-0.05602
0.0004	0.022918	1.000218	0.000218	10.809671	0.09251	0.713	1.004	1.072403	1.01688	-0.01288
0.000475	0.027215	1.000259	0.000259	9.919293	0.100814	0.715	1.026	1.069808	1.01928	0.00672
0.0005	0.028648	1.000273	0.000273	9.668020	0.103434	0.708	1.025	1.068621	1.02039	0.00461
0.0006	0.034377	1.000327	0.000327	8.825250	0.113311	0.685	1.019	1.065104	1.02367	-0.00467
0.0010	0.057296	1.000545	0.000545	6.834755	0.146311	0.617	1.000	1.055113	1.03298	-0.03298

Conclusion: Rocking stability reaching at an approximate angle of 0.03 degrees.

		cos	sin	$f_1(\Theta) = \cos\Theta + a\sin\Theta$
0.0100	0.572956	0.999950	0.010000	1.005404
0.0200	1.145913	0.999800	0.019999	1.010708
0.0500	2.864782	0.998750	0.049979	1.026012
0.1000	5.729565	0.995004	0.099833	1.049459
0.2000	11.45913	0.980067	0.198669	1.088432
0.3000	17.18869	0.955336	0.295520	1.116529
0.4000	22.91826	0.921061	0.389418	1.133471
0.4990	28.59053	0.878062	0.478548	1.139088

Response Spectra (2007) Ref. 2.2.24

		NEW R-S, DBGM-2	
		HOR	VER
Period (s)	**Freq. (Hz)**	**SA (10.0%)**	**SA (10.0%)**
0.010	100.000	0.4537	0.3194
0.011	91.116	0.4700	0.3369
0.012	81.113	0.4911	0.3600
0.014	70.548	0.5061	0.3694
0.017	59.948	0.5207	0.3885
0.020	49.770	0.5394	0.4129
0.025	40.370	0.5627	0.4450
0.034	29.837	0.6031	0.5004
0.050	20.092	0.6723	0.5941
0.100	10.000	0.9100	0.6243
0.110	9.112	0.9032	0.6027
0.123	8.111	0.8920	0.5746
0.142	7.055	0.8794	0.5414
0.167	5.995	0.8659	0.5032
0.201	4.977	0.8326	0.4625
0.248	4.037	0.7733	0.4217
0.335	2.984	0.6926	0.3713
0.498	2.009	0.5823	0.3128
1.000	1.000	0.3212	0.1674
1.123	0.890	0.2849	0.1492

Period (s)	Freq. (Hz)	NEW R-S, DBGM-2 HOR SA (10.0%)	NEW R-S, DBGM-2 VER SA (10.0%)
1.262	0.793	0.2527	0.1336
1.417	0.706	0.2243	0.1190
1.668	0.600	0.1856	0.1015
2.009	0.498	0.1473	0.0841
2.477	0.404	0.1080	0.0589
3.351	0.298	0.0658	0.0339
4.978	0.201	0.0332	0.0157
10.000	0.100	0.0093	0.0042

Formulae used from Reference 2.2.25

$$f_1(\theta_o) = \cos(\theta_o) + (a)\sin(\theta_o) \qquad \text{[Eq. A-5(a)]}$$

$$f_e = \frac{1}{2\pi}\left[\frac{2(f_1(\theta_o) - 1)g}{C_I \theta_o^2 h}\right]^{1/2} \qquad \text{[Eq. A-6(a)]}$$

$$F_V = \left[1 + \left(\frac{a(SAV)}{F_H(SAH)}\right)^2\right]^{1/2} \qquad \text{[Eq. A-5(c)]}$$

$$SAH_{CAP} = \frac{2g(f_1(\theta_o) - 1)}{F_H F_V \theta_o} \qquad \text{(Eq. A-5)}$$

<u>Verification of values in first row of Table for **NEW R-S, DBGM-2 (10% Damping)**</u>**:**

Given:

$H := 22 \quad ft$ Height of Aging Overpack, [ASCE 43-05, Ref. 2.2.17]

$B := 12 \quad ft$ Base diameter of Aging Overpack, [ASCE 43-05, Ref. 2.2.17]

Assume the mass is uniformly distributed throughout the rigid body. Thus, the center of height, h, and horizontal distance, b, from the rocking corner are,

$h := \frac{H}{2} \qquad h = 11 \quad ft$ [ASCE 43-05, Eq. B-30(a)]

$b := \frac{B}{2} \qquad b = 6 \quad ft$ [ASCE 43-05, Eq. B-30(b)]

From Eqs. 7-2(a) and 7-2(b), the aspect ratio, a, and instability angle, α, are,

$a := \frac{b}{h} \qquad a = 0.545$

$\alpha := \text{atan}(a) \qquad \alpha = 0.499$

$F_H := 1.0$ [ASCE 43-05, Ref. 2.2.25, Eq. B-32(a)]

$C_1 := \left(\frac{4}{3}\right)\cdot\left(1 + a^2\right) \qquad C_1 = 1.73$ [ASCE 43-05, Ref. 2.2.25, Eq. A-6(f)]

$CR := \left[1 - \left(\frac{2\cdot a^2}{C_1}\right)\right] \qquad CR = 0.656$ [ASCE 43-05, Ref. 2.2.25, Eq. A-6(e) & page 37 (For CR = 0.656, say 0.7, βe = 11.3%; therefore, use **10% damping**)]

NEW R-S, DBGM-2 (10% Damping) - (Equations are used from Reference 2.2.25 and are defined below):

$\theta := 0.0001$ radians

$\theta deg := \theta\cdot\left(\frac{180}{\pi}\right) \qquad \theta deg = 5.73\times 10^{-3}$ degrees

$f_1 := \cos(\theta) + (a)\cdot\sin(\theta) \qquad f_1 = 1.000055$ [ASCE 43-05, Ref. 2.2.25, Eq. A-5(a)]

For (f_1 - 1):

$fo := f_1 - 1$ $\quad\quad$ $fo = 5.45\times 10^{-5}$

Determine the effective rocking frequency, f_e, corresponding to any θ and effective damping, βe, where,

$g := 32.2$

$$fe := \left(\frac{1}{2\cdot\pi}\right)\cdot\sqrt{\frac{2\cdot fo\cdot g}{C_1\cdot\left(\theta^2\right)\cdot h}} \quad\quad fe = 21.622 \quad\quad \text{[ASCE 43-05, Eq. A-6(a)]}$$

The next step is to take the inverse of the effective rocking frequency, f_e,

$$f := \frac{1}{fe} \quad\quad f = 0.046 \quad\quad \text{(Period)}$$

Ratio of vertical to horizontal spectral acceleration determined at the effective rocking frequency, f_e, and effective damping of 10%. This data was computed by iterating between the data given from the Response Spectra, Ref. 2.2.24,

SAV, g @ DBGM2 (10% Damping), (spectral vertical acceleration at effective rocking frequency)

$$x := \begin{pmatrix} 20.092 \\ 29.837 \end{pmatrix} \quad\quad y := \begin{pmatrix} 0.5941 \\ 0.5004 \end{pmatrix} \quad\quad xo := 21.622$$

$\text{linterp}(x, y, xo) = 0.579$ $\quad\quad$ $SAV := \text{linterp}(x, y, xo)$ $\quad\quad$ $SAV = 0.579$

SAH, g @ DBGM2 (10% Damping), (spectral horizontal acceleration at effective rocking frequency)

$$x := \begin{pmatrix} 20.092 \\ 29.837 \end{pmatrix} \quad\quad y := \begin{pmatrix} 0.6723 \\ 0.6031 \end{pmatrix} \quad\quad x1 := 21.622$$

$\text{linterp}(x, y, x1) = 0.661$ $\quad\quad$ $SAH := \text{linterp}(x, y, x1)$ $\quad\quad$ $SAH = 0.661$

Correction for probabilistically combined vertical ground motion, Fv, is computed as,

$$Fv := \sqrt{1 + \left(\frac{a \cdot SAV}{F_H \cdot SAH}\right)^2} \qquad Fv = 1.108$$

[ASCE 43-05, Eq. A-5(c)]

The horizontal spectral acceleration capacity, SAHcap, corresponding to any rotation angle, θ, is computed as,

$$SAHcap := \frac{2 \cdot (fo)}{F_H \cdot Fv \cdot \theta} \qquad SAHcap = 0.984$$

[ASCE 43-05, Eq. A-5]

The resultant demand, from the difference of the demand and the capacity, is determined as,

$$D := SAH \qquad C := SAHcap \qquad D - C = -0.323$$

Interpolation of response Spectra for Frequency in calculation above using Mathcad.

$S_{AV,\,g}$ DBGM2 (10% Damping)

$x := \begin{pmatrix} 20.092 \\ 29.837 \end{pmatrix}$ $y := \begin{pmatrix} 0.5941 \\ 0.5004 \end{pmatrix}$ $x_{loc} := 21.622316$

$\text{linterp}(x, y, x_{loc}) = 0.579$

$x := \begin{pmatrix} 10.000 \\ 20.092 \end{pmatrix}$ $y := \begin{pmatrix} 0.6243 \\ 0.5941 \end{pmatrix}$ $x_{loc} := 15.288585$

$\text{linterp}(x, y, x_{loc}) = 0.608$

$x := \begin{pmatrix} 10.000 \\ 20.092 \end{pmatrix}$ $y := \begin{pmatrix} 0.6243 \\ 0.5941 \end{pmatrix}$ $x_{loc} := 12.482505$

$\text{linterp}(x, y, x_{loc}) = 0.617$

$x := \begin{pmatrix} 10.000 \\ 20.092 \end{pmatrix}$ $y := \begin{pmatrix} 0.6243 \\ 0.5941 \end{pmatrix}$ $x_{loc} := 10.809671$

$\text{linterp}(x, y, x_{loc}) = 0.622$

$x := \begin{pmatrix} 9.112 \\ 10.000 \end{pmatrix}$ $y := \begin{pmatrix} 0.6027 \\ 0.6243 \end{pmatrix}$ $x_{loc} := 9.668020$

$\text{linterp}(x, y, x_{loc}) = 0.616$

$x := \begin{pmatrix} 8.111 \\ 9.112 \end{pmatrix}$ $y := \begin{pmatrix} 0.5746 \\ 0.6027 \end{pmatrix}$ $x_{loc} := 8.825250$

$\text{linterp}(x, y, x_{loc}) = 0.595$

$x := \begin{pmatrix} 5.995 \\ 7.055 \end{pmatrix}$ $y := \begin{pmatrix} 0.5032 \\ 0.5414 \end{pmatrix}$ $x_{loc} := 6.834755$

$\text{linterp}(x, y, x_{loc}) = 0.533$

$S_{AH,\,9}$ DBGM2 (10% Damping)

$x := \begin{pmatrix} 20.092 \\ 29.837 \end{pmatrix}$ $y := \begin{pmatrix} 0.6723 \\ 0.6031 \end{pmatrix}$ $x_{loc} := 21.622316$

$\text{linterp}(x, y, x_{loc}) = 0.661$

$x := \begin{pmatrix} 10.000 \\ 20.092 \end{pmatrix}$ $y := \begin{pmatrix} 0.9100 \\ 0.6723 \end{pmatrix}$ $x_{loc} := 15.288585$

$\text{linterp}(x, y, x_{loc}) = 0.785$

$x := \begin{pmatrix} 10.000 \\ 20.092 \end{pmatrix}$ $y := \begin{pmatrix} 0.9100 \\ 0.6723 \end{pmatrix}$ $x_{loc} := 12.482505$

$\text{linterp}(x, y, x_{loc}) = 0.852$

$x := \begin{pmatrix} 10.000 \\ 20.092 \end{pmatrix}$ $y := \begin{pmatrix} 0.9100 \\ 0.6723 \end{pmatrix}$ $x_{loc} := 10.809671$

$\text{linterp}(x, y, x_{loc}) = 0.891$

$x := \begin{pmatrix} 9.112 \\ 10.000 \end{pmatrix}$ $y := \begin{pmatrix} 0.9032 \\ 0.9100 \end{pmatrix}$ $x_{loc} := 9.668020$

$\text{linterp}(x, y, x_{loc}) = 0.907$

$x := \begin{pmatrix} 8.111 \\ 9.112 \end{pmatrix}$ $y := \begin{pmatrix} 0.8920 \\ 0.9032 \end{pmatrix}$ $x_{loc} := 8.825250$

$\text{linterp}(x, y, x_{loc}) = 0.9$

$x := \begin{pmatrix} 5.995 \\ 7.055 \end{pmatrix}$ $y := \begin{pmatrix} 0.8659 \\ 0.8794 \end{pmatrix}$ $x_{loc} := 6.834755$

$\text{linterp}(x, y, x_{loc}) = 0.877$