Evaluation of Reserve Shear Capacity of Bridge Pier Caps Using the Deep Beam Theory

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16. Abstract

Many bridge pier caps are deep due to short shear spans. When analyzed using the slender beam theory (i.e., the sectional method), a large number of pier caps are found to be shear-overloaded even though they don't exhibit any noticeable cracking or signs of distress. AASHTO LRFD 2017 recommends the use of either a strut-and-tie or nonlinear finite element model for the analysis and design of deep members. Both methods are more sophisticated and require more effort than the sectional method. The objective of this study was to simplify the strut-and-tie method for pier caps to obtain larger and less conservative shear capacity predictions. For this purpose, a solution algorithm (computer program) was developed based on Section 5.8.2 Strut-and-Tie Method of AASHTO LRFD 2017. The program, named STM-CAP (*Strut-and-Tie Method for pier CAPs*), is implemented in Microsoft Excel using Visual Basic macro codes. An adaptive graphical solution procedure was employed to minimize the input errors and give the analyst options for optimizing the automatically generated model. STM-CAP calculates the utilization ratio for every element, which reflects the condition (overload or reserve capacity percentage) of the pier cap. If overloaded, STM-CAP indicates the calculated failure mode and its location. Suitable rehabilitation methods and load limits can then be determined accordingly. STM-CAP is verified using a general-purpose strut-and-tie software, CAST (*Computer Aided Strut and Tie*) and VecTor2 (a nonlinear finite element analysis software) for eight existing pier caps located in Ohio. In addition, the sectional method calculations were performed to demonstrate the extra shear capacity predictions obtained from the strut-and-tie method. The strut-and-tie method predicted 2 to 3 times higher shear capacities for beams with shear span-to-depth ratio (a/d) of 0.50. The predictions by STM-CAP and the sectional method converge as the a/d ratios approach 3.0. The research results have a potential to result in significant cost savings by rehabilitating fewer pier caps and reducing the associated construction work and traffic disruption. The developed program, STM-CAP, can also be used when load rating concrete pier caps.

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1. Executive Summary

The AASHTO LRFD (Load and Resistance Factor Design) Bridge Design Specification 2017 contains two main analysis methods for the design of reinforced concrete members: the Sectional Method and the Strut-and-Tie Method (STM). The sectional method requires checking the shear/moment capacities at critical sections based on the plane-sections-remain-plane hypothesis (i.e., the slender beam theory). STM, on the other hand, does not rely on this hypothesis and thus is suitable for the analysis of deep beams, which exhibit nonlinear strain gradient. STM is a graphical method and requires more effort and experience than the sectional method. In civil engineering practice, the sectional method is the most popular method and dominantly used for analyzing and load rating existing pier caps even if they are deep. If a deep beam is analyzed by a sectional method, invalid and typically overly-conservative (i.e., low) shear capacities are obtained. This practice may result in incorrectly identifying cap beams as shear-overloaded; these beams may in fact even have reserve capacities when analyzed by a proper analysis method such as STM.

STM is the algorithmic basis for our newly developed program, STM-CAP (Strut-and-Tie Method for pier CAPs). The program is embedded in Microsoft Excel to eliminate the need to install and learn a new software. STM-CAP uses Visual Basic Application (VBA) coding and provides graphical representation of the model to help the analyst better understand the system and identify potential input errors. STM-CAP is divided into several sections covering various aspects of the input parameters and analysis output results. STM-CAP uses factored loads and factored material resistances and thus performs an LFRD analysis. A utilization ratio of 1.0 indicates that the cap has a sufficient factor of safety as per the LFRD method.

STM-CAP was developed for the analysis of deep pier caps subjected to static girder loads for both symmetrical and asymmetrical deep pier caps, providing analysis of symmetrical pier caps with up to eight columns and asymmetrical pier caps with up to four columns. STM-CAP models the pier cap with a truss model consisting of ties, struts, and nodes. Ties represent the tension truss elements; struts represent the compressive truss elements; and nodes are the connections of the truss analogy. It considers two types of ties: horizontal ties for main bars and vertical ties for stirrup ties. The generated truss model can be further adjusted using the vertical ties if required by the user for the optimization of the STM model. The member forces for the STM truss model are determined using the matrix stiffness method considering uniform stiffness for each member. The capacity for each STM element is determined as per the AASHTO LRFD 2017 Bridge Design Specification. The nodal checks are performed for each member and the capacities are determined as the minimum of the capacity of the STM member and its adjoining nodes. STM-CAP calculates the utilization ratio (ratio of member force to member capacity) for each STM member to reflect the condition (either overloaded or reserve capacity) of the pier cap under the application of the factored loads. A utilization ratio of 0.80, for example, indicates that the pier cap has 80% of its capacity in use and has approximately 20% reserve capacity remaining. Using the utilization ratio, overloaded bridges can be categorized, and limited strengthening funds can be directed to the caps with the largest utilization ratios. STM-CAP also indicates the governing failure mode and location of the failure, thereby facilitating the strengthening of cap beams at the correct locations.

A total of eight pier caps, the design drawings of which were received from ODOT, were modeled using STM-CAP. They consist of cantilevered, non-cantilevered, symmetrical, and asymmetrical pier caps with varying numbers of columns and girder loads. The same pier caps were also modeled with CAST (Computer Aided Strut-and-Tie) and VecTor2 (a nonlinear finite element software). The results from each method were compared to assess the accuracy and validate the calculations of the STM-CAP. The utilization ratios, governing behaviors, and failure modes were compared to validate the accuracy of the STM-CAP program. The CAST was based on the principle of STM conceptualization similar to STM-CAP, therefore the comparison was justified. Five out of eight pier caps modeled by CAST were also modeled using VecTor2, a nonlinear finite element analysis software, to assess the global response of pier cap. Also, the comparison of the STM with the stress distribution from the nonlinear Finite Element Method (FEM) was performed based on the concept of utilization ratio which is the ratio of stresses at the factored loads divided by the strength of the material. In addition, the nonlinear load-displacement responses obtained from nonlinear FEM was used to obtain the global capacity of the pier caps.

Although the sectional method is not recommended for deep beam caps, it was used for comparison with the STM-CAP to demonstrate that the sectional method underestimates the shear capacity for pier caps. The shear utilization ratios for twenty-one regions with different a/d ratios obtained from the analysis of five different bridges were compared. The shear utilization ratio at critical sections using the sectional method was calculated as the ratio of shear force to the shear capacity under the AASHTO provisions. The developed program STM-CAP was used to determine the utilization ratios for each STM member. The shear utilization ratio from the STM is the utilization ratio of the critical inclined or vertical element of the STM-CAP at each critical section. The utilization ratio and capacity are inversely proportional; for example, the higher the utilization ratio, the lower the capacity prediction for the same load. Thus, it is expected that higher utilization ratios were obtained from the sectional method as compared to the STM since most of the regions in the pier caps are deep.

2. Project Background

The increase in traffic and transport freight over the past decade has significantly increased the loading on bridge structures. Ohio was the ninth-ranked state with the highest number of deficient bridges in 2016 (two positions up from its eleventh-ranking in 2015) and the cost to replace all structurally-deficient bridges and rehabilitate the most urgent two-thirds is approximately $3.6 billion dollars (ASCE 2009, 2017). Such a prohibitive cost requires ODOT to use accurate analysis methods to correctly identify the overloaded bridges.

'Pier caps,' or 'bent caps,' transfer the load from the girders to the columns. Bridge pier caps are unique structures due to the short shear span over which the girder loads are applied. A beam for which the distance between the applied load and the reaction point is less than about twice the member depth is referred to as a deep beam. Most pier caps are *'deep beams'* that possess additional shear strength due to the formation of the strut action. Unlike slender beams, deep beams transfer shear forces to supports through compressive stresses rather than shear stresses. The diagonal cracks in deep beams eliminates the inclined principal tensile stresses required for beam action and leads to a redistribution of internal stresses so that the beam acts as a tied arch known as strut action. The AASHTO LRFD code began to include the deep beam methods in 1994. Since the average age of the bridges in Ohio is over forty years, most in-service bridges were not designed considering the deep beam effects and thus possess a hidden reserve shear capacity.

The analysis methods used for the shear strength evaluation of bridges, by ODOT and most other DOTs, are typically based on the slender beam theory (i.e., sectional analysis). This theory neglects the deep beam action and cannot capture the additional shear capacity. When analyzed by engineers using the traditional sectional methods, deep beams are found to be shear overloaded although they may not exhibit any noticeable cracking or signs of distress. This casts doubt on the currently used analysis method for pier caps. Consequently, pier caps with sufficient shear strength may be incorrectly identified as structurally deficient. To reduce rehabilitation costs, ODOT needs practical analysis methods that account for deep beam action in evaluating the shear capacities of pier caps.

3. Research Context

3.1 Research Objectives

There is limited public funding for the rehabilitation and strengthening of deficient bridges. Because of this, it is imperative to use the proper analysis method to correctly identify and rank the overloaded bridges. The main objective of this study is to explore innovative strategies to reduce the complexity of the STM to a level comparable to sectional methods for analyzing deep cap beams. It seeks to create a computer program with strong graphical capabilities to automatically generate efficient STM models while intuitively educating practicing engineers in the correct use of STM. To check the accuracy of the developed STM tool, a number of bridge pier caps are to be modeled using a) the STM developed tool, b) CAST (Computer Aided Strut-and-Tie), a research purpose STM software, and c) the nonlinear finite element analysis method, the latter of which is suitable for a more detailed investigation of pier caps.

A secondary objective is to compare the shear strength predictions obtained from the sectional method and understand if sectional methods always underestimate the shear capacities of deep beams, and, if so, to what extent and under what conditions.

3.2 Literature Search

The literature search was performed in the proposal stage of the project and during the continuation of the research project.

In 1964, Kani performed a series of tests to calculate the load carrying capacity of fourteen reinforced concrete beams with varied a/d ratio. The results of a test done by Kani is shown in **Figure 1.** He found that STM was better than the sectional method for the analysis and design of deep beams, whereas, the sectional method was better at predicting shear strength of slender beams. Therefore, this work verified that a combination of both methods, the sectional method and STM, should be used for the analysis and design of beams. The sectional method should be used for slender beams (a/d ratio > 2.5) and STM should be used for deep beams (a/d ratio < 2.5).

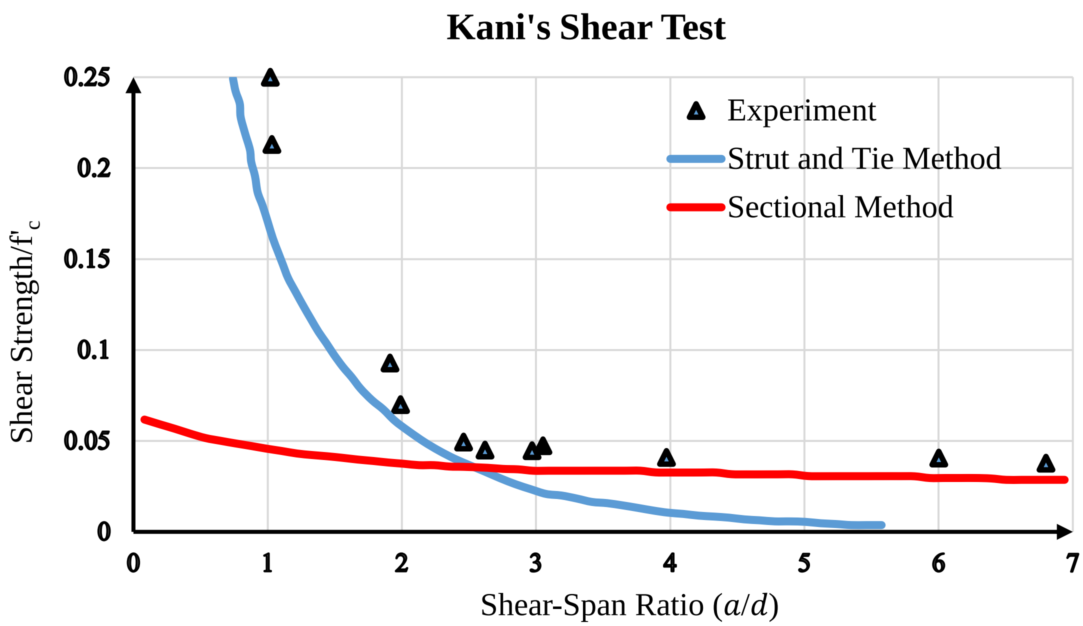


Figure 1 Shear strength vs a/d ratio (Kani, 1964).

Ferguson (1964) conducted a notable experiment on thirty-six 36” deep pier cap overhangs at the University of Texas. The variables studied were shear span, bar anchorage length, skin reinforcement, grade and area of rebar, amount of shear reinforcement, etc. The test was conducted until failure of the pier cap overhang. One key finding was that, within a shear span-to-depth ratio (a/d) 0.5 to 1.2, the ultimate shear strength was found to be conservatively higher than the strength calculated by the previously used method (ordinary beam theory). This finding yielded a consistent result to Kani’s.

Denio et al. (1995) conducted an experiment on six pier cap specimens at 30% scale. These pier caps were loaded to failure under eleven static loads and different analysis methods were compared. In all specimens, it was found the load on the pier caps was primarily carried by the action of the tied arch from the load base plates to the column. The strut-and-tie models used were more accurate than conventional design methods in predicting the capacity of the pier caps due to the modeling of the compression arch action observed during testing. Denio et al. recommended using the strut-and-tie method for design and analysis of pier caps as it gave the best correlation with test results, modeled true behavior, and was still conservative.

A research team under the direction of Dr. Higgins at Oregon State University conducted full-scale testing of pier caps with 1950’s vintage details common in the State of Oregon. They demonstrated that deep cap beams failed in shear at load capacities much higher than those calculated by the slender beam theory. They also compared a number of analysis methods and found that the program VecTor2 provided one of the best load capacity estimates (Senturk & Higgins 2010). Dr. Bechtel at Georgia Institute of Technology conducted full-scale testing of seven pier caps typical to the State of Georgia and showed the suitability of the strut-and-tie method (Bechtel 2012). A University of Minnesota study calculated the ultimate capacities of a number of internationallytested pier caps using a variety of analysis methods. They found that the strut-and-tie method was capable of predicting the shear capacities (Milde et al. 2005).

The literature reviews highlighted shear failure as the prominent type of failure in pier caps, most of which were typically deep beams. Different analytical methods were used to predict the ultimate capacity of the beams. It was found that STM is better at predicting ultimate capacity. The other tested methods yielded highly conservative results and thus were not applicable methods for the analysis of deep beams.

4. Research Approach

STM is a truss model in which the stress field in the structural concrete is equivalent to the hypothetical simple uniaxial truss to give a proper and definite load path (see **Figure 2**). The truss analogy consists of struts, ties, and nodes. STM elements subjected to tension are ties and those subjected to compression are struts. The intersection of these ties and struts are called nodes. The ties represent the rebar (longitudinal or transverse) and the struts and nodes represent the concrete in compression.

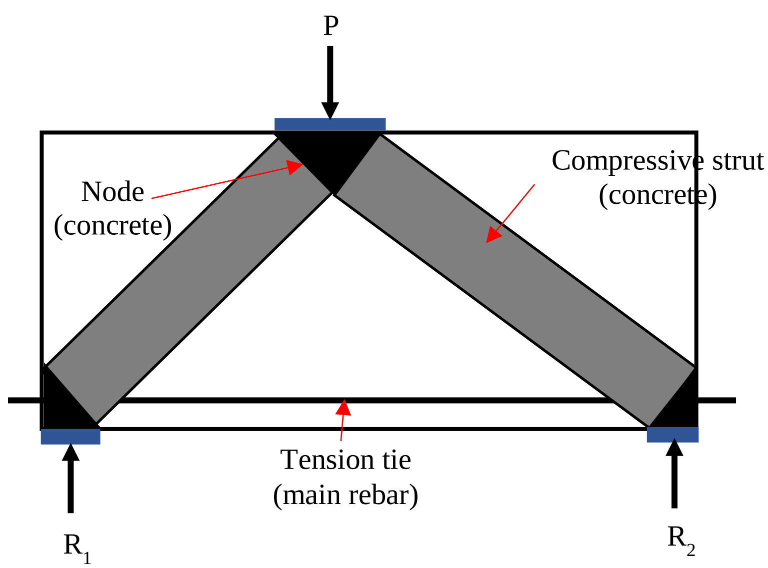


Figure 2 Strut-and-tie model in a beam.

4.1 Development, Testing, Debugging and Refinement of the spreadsheet, STM-CAP

STM is a graphical method and requires more effort and experience than the sectional method. Multiple STM models can be developed for the same bridge—some of which are more efficient (and less conservative) than the others. In addition, STM is not typically taught in undergraduate Civil Engineering education and many practicing engineers are not familiar with it. Also, there are many bridge pier caps and each pier cap analysis take a significant amount of time with hand-calculation. Thus, the programming of STM is required. Because of this, STM was used to develop the spreadsheet program STM-CAP or *Strut-and-Tie Method for pier CAPs.*

STM-CAP is a spreadsheet program for the analysis of deep pier caps subjected to girder loads. It is divided into several sections. The initial sections include the input parameters while the subsequent sections present the analysis results. A major objective was to use graphical solutions as part of the analysis process to help the analyst better understand the system and identify potential errors. The input, calculation details, and the output process are presented in **Figure 3** and **Figure 4**.

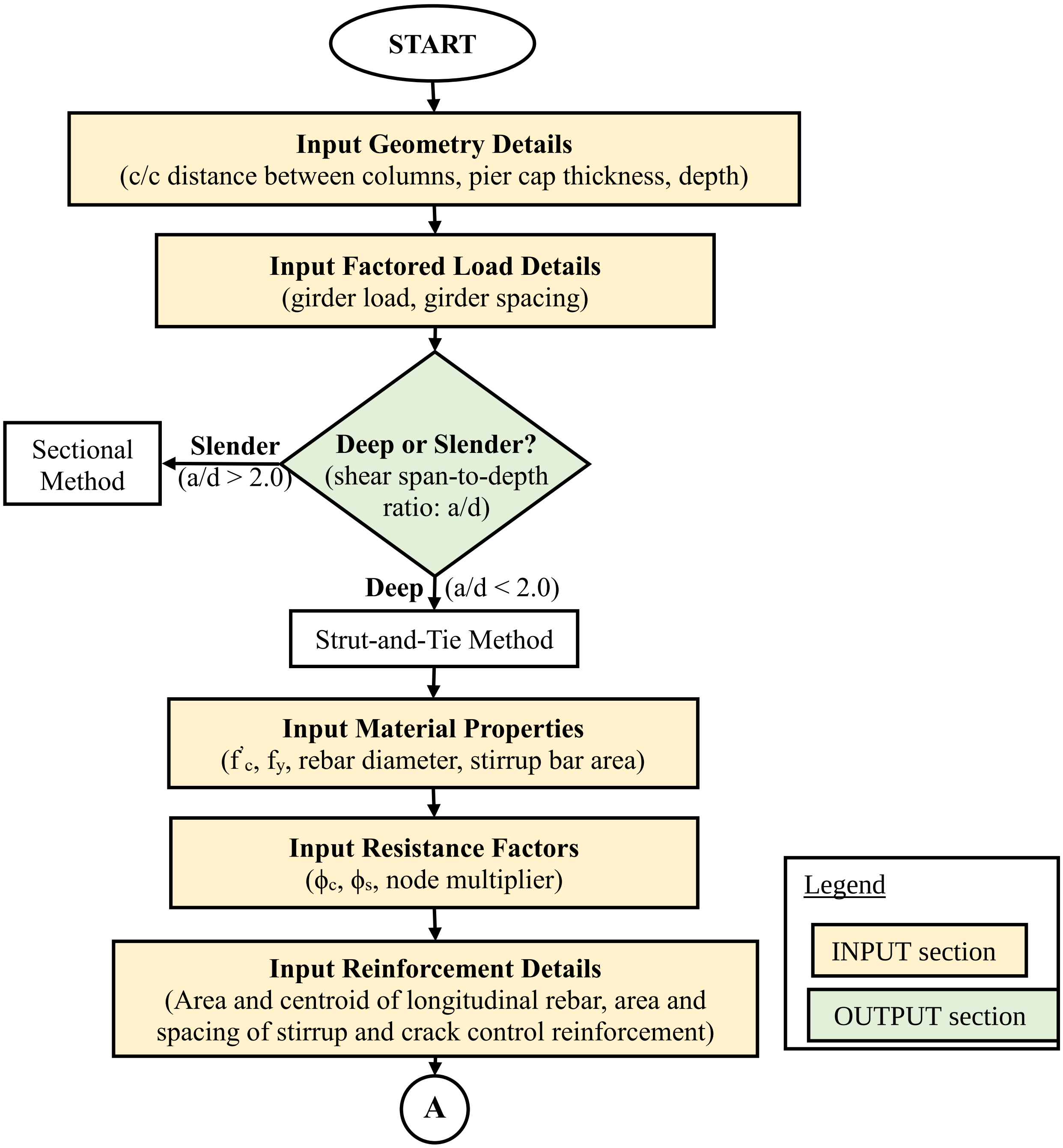


Figure 3 Flowchart for the STM-CAP solution procedure (part A).

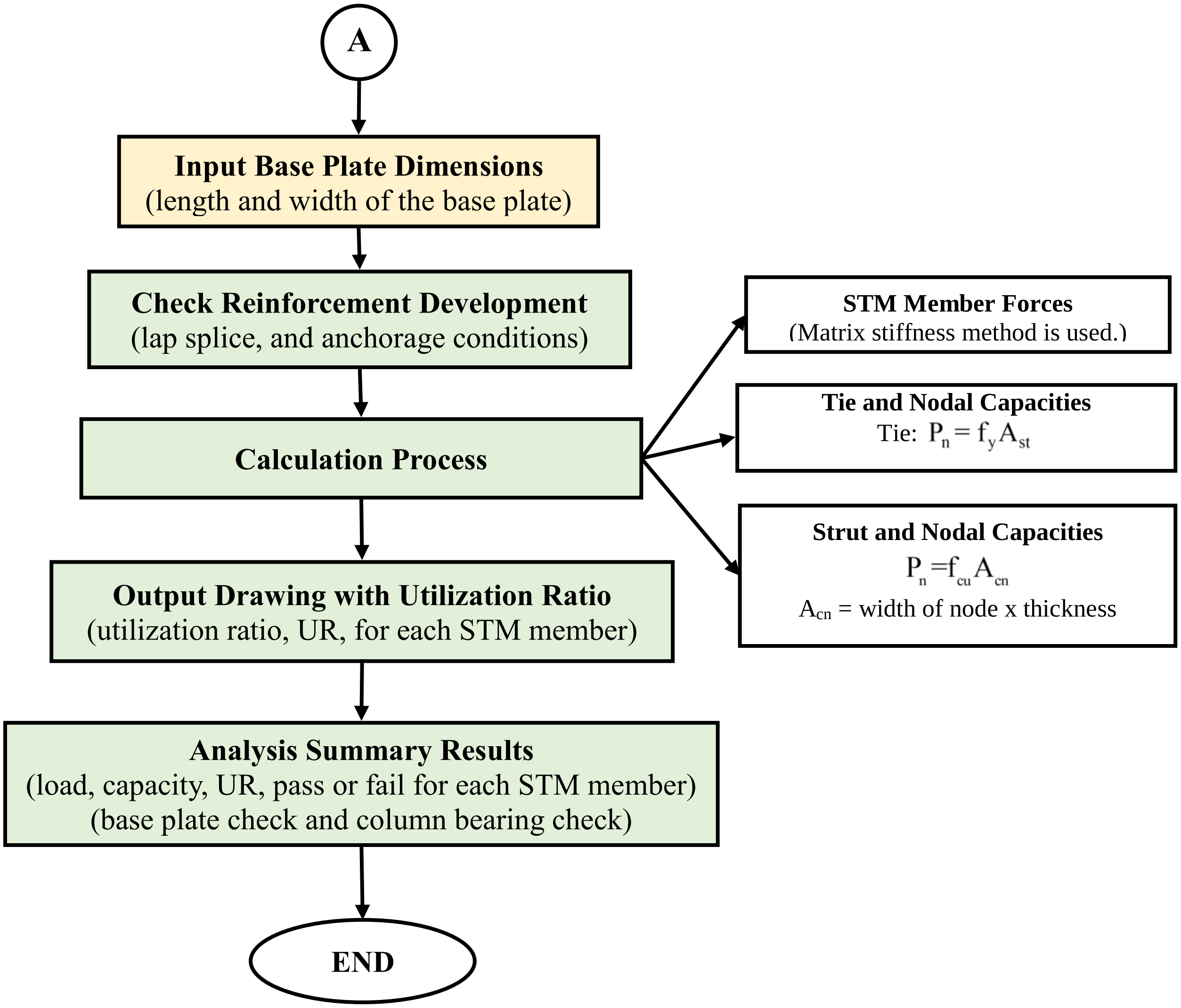


Figure 4 Flowchart for the STM-CAP solution procedure (part B).

Notation

P_n = nominal resistance of a STM member (kip);
A_{st} = total area of longitudinal rebar in the tie (in^2);
f_y = yield strength of mild steel (ksi);
f_{cu} = limiting compressive stress (ksi) as specified in AASHTO;
A_{cn} = effective cross-sectional area of the node face (in.^{2});
α_s =smallest angle between the compressive strut and adjoining tension ties;

STM-CAP was developed for the analysis of deep pier caps subjected to static girder loads for both symmetrical and asymmetrical deep pier caps, including analysis of symmetrical pier caps with up to eight columns and asymmetrical pier caps with up to four columns. For symmetrical pier caps, the input and output of the analysis are limited up to the centerline. In the analysis for asymmetrical pier caps, the full pier cap analysis is performed.

The program first requires basic details to be input for the pier cap to be investigated, such as Bridge Name, SFN Number, PID Number, Pier Number, etc., followed by geometry input and factored loads input. A drawing based on these inputs is generated, via VBA, to allow the user to inspect for any mistakes and confirm the accuracy of the input.

STM-CAP initially determines if a pier cap is deep or not. Based on the factored load and geometry input, STM-CAP calculates the shear span-to-depth ratio for every region. If the ratio is less than 2.0, it is a deep region. If the beam qualifies as deep, further inputs are to be made. The user is notified if the conventional sectional method should be used.

The additional input for STM analysis includes the material properties and resistance factors. STM-CAP uses factored loads and factored material resistances and thus performs an LRFD analysis. These factors can be modified by the user when new editions of the code require different values.

The length and width of the bearing plates (base plates) are required when calculating the width of the nodal zone as per AASHTO LRFD. They are also used to perform bearing checks (to check the adequacy of the base plate to transfer the load from the girder to the pier cap). STM-CAP performs the reinforcement anchorage and development length checks to ensure that the longitudinal bars are adequately developed. Otherwise, required strength reductions are automatically made for the tension tie capacity.

STM-CAP models the pier cap with a truss model consisting of ties, struts, and nodes. The member forces for the STM truss model are determined using the matrix stiffness method assuming uniform stiffness for each member. The capacity for each STM element is determined as per AASHTO LRFD Bridge Design Specification. The nodal checks are performed for each member and the capacity is determined as the minimum capacity of the STM member and its adjoining nodes. STM-CAP calculates the utilization ratio (ratio of member force to member capacity) for each STM member. An output STM model with the utilization ratios is generated to provide an overview of the analysis results as shown in **Figure 5**. The model shown is color-coded: 'red' represents 'ties,' 'blue' represents 'struts,' and the 'intersections' represents the 'nodes.'

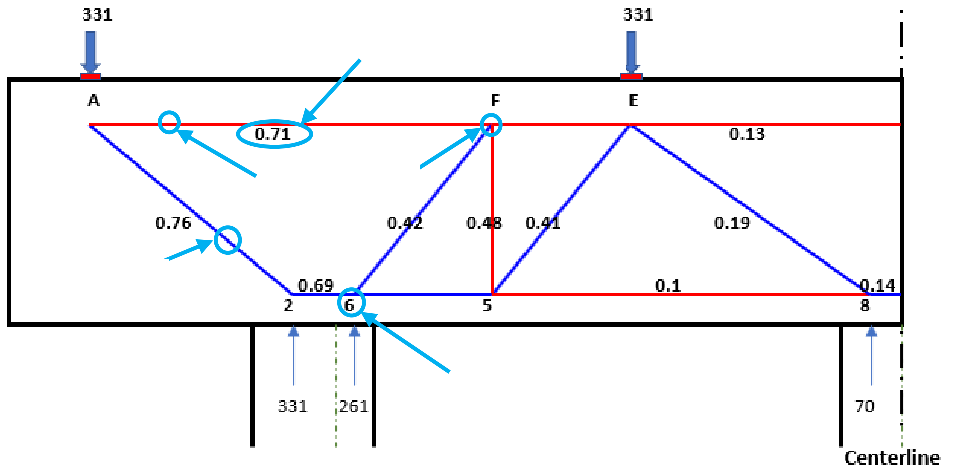
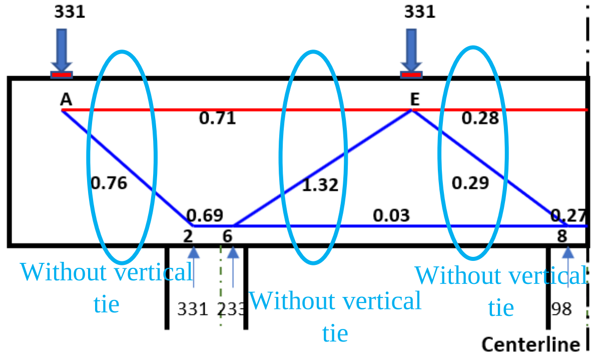
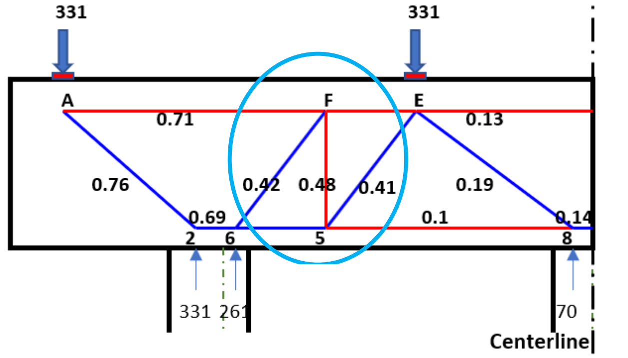


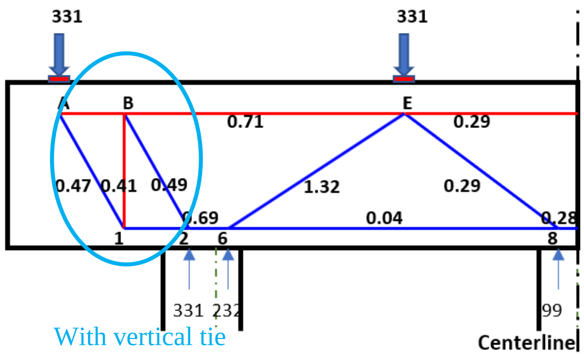
Figure 5 STM-CAP output model

The behavior of the inclined member depends upon the angle of inclination with respect to the horizontal plane. With a higher angle of inclination, the inclined member force decreases. Hence, the STM model is selected to obtain the minimum utilization ratio for the pier cap. The process of obtaining minimum utilization ratio is known as optimization of the model to create an efficient model. In STM-CAP, the truss model can be adjusted by the user with a combination of vertical ties by toggling between the inclined member without vertical ties and the inclined members with vertical ties or combination of both (see **Figure 6**). The utilization ratios are updated along with the updated model, which gives the confirmation for an efficient truss model. **Figure 6** shows the different combinations for vertical ties used to obtain an efficient truss model. It is seen that the truss model (d) would be the best model for the analysis of this sample pier cap.

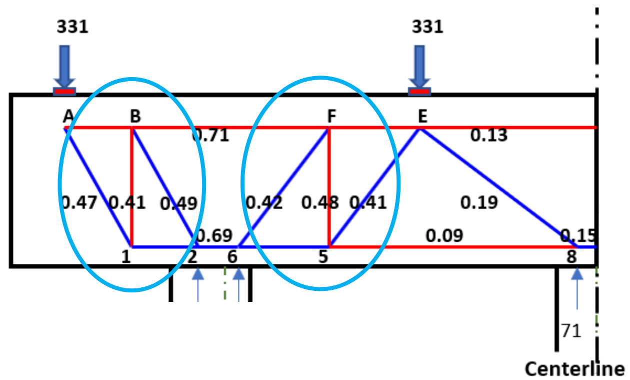


(a)Utilization ratios without vertical





(c)Utilization ratios with vertical ties only for first inclined member



(d)Utilization ratios with vertical ties for first and second inclined member

Figure 6 Optimization of utilization ratios with various truss models.

The output model is followed by the STM-CAP output summary (**Figure 7**). This section summarizes all the results from the calculations performed for struts, ties, nodes and bearing checks. It tabulates the STM member force, capacity, and utilization ratios for each STM member.

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down

Input Option	Summary				
	Member Code	***Force (k)***	***Capacity (k)***	***Utilization Ratio***	***Result***
	A-F	533	754	0.71	PASS
	E-K	95	754	0.13	PASS
	2-6	-533	-771	0.69	PASS
	5-8	37	378	0.10	PASS
	8-12	-95	-680	0.14	PASS
	B-1	-	-	0.00	-
	F-5	261	547	0.48	PASS
	H-7	-	-	0.00	-
0	A-2	-627	-826	0.76	PASS
1	F-6	-386	-923	0.42	PASS
	E-5	-386	-937	0.41	PASS
0	E-8	-149	-782	0.19	PASS

Figure 7 STM-CAP summary table.

4.2 Verification of the STM-CAP results by CAST

A total of eight pier caps beams were modeled using STM-CAP and CAST software. The results from each method were compared to assess the accuracy and validate the calculations of the STM-CAP. CAST is a general-purpose linear-elastic strut-and-tie modeling software used for the analysis and design of disturbed regions. CAST is mainly used for research purposes and is primarily based on ACI codes. CAST was customized with manually calculated factors to work with AASHTO provisions.

In STM-CAP, a truss model is generated which may be an optimized or an unoptimized model. The truss model can be further adjusted by the user to get an optimized model. The truss model comparison includes the direct truss model from STM-CAP, without any further optimization to check the suitability for each case with CAST. Since STM-CAP and CAST work on the same principle of strut-and-tie, the comparison with any model (optimized or unoptimized) selection is valid. The modeling and analysis process using CAST first requires defining the material properties, thickness, and boundaries. The strut-and-tie model is sketched, and the ultimate girder loads and support conditions for the given pier cap are applied. The truss model is then solved to get the strut and tie member forces. The strut types, the tie types, and the node types are defined and assigned to each strut, tie, and node created. The analysis model is *'run'* to get the analysis result. The member forces, utilization ratios, girder loads, support reactions, etc. are the analysis outputs from CAST. A sample comparison is shown in **Figure 8**.

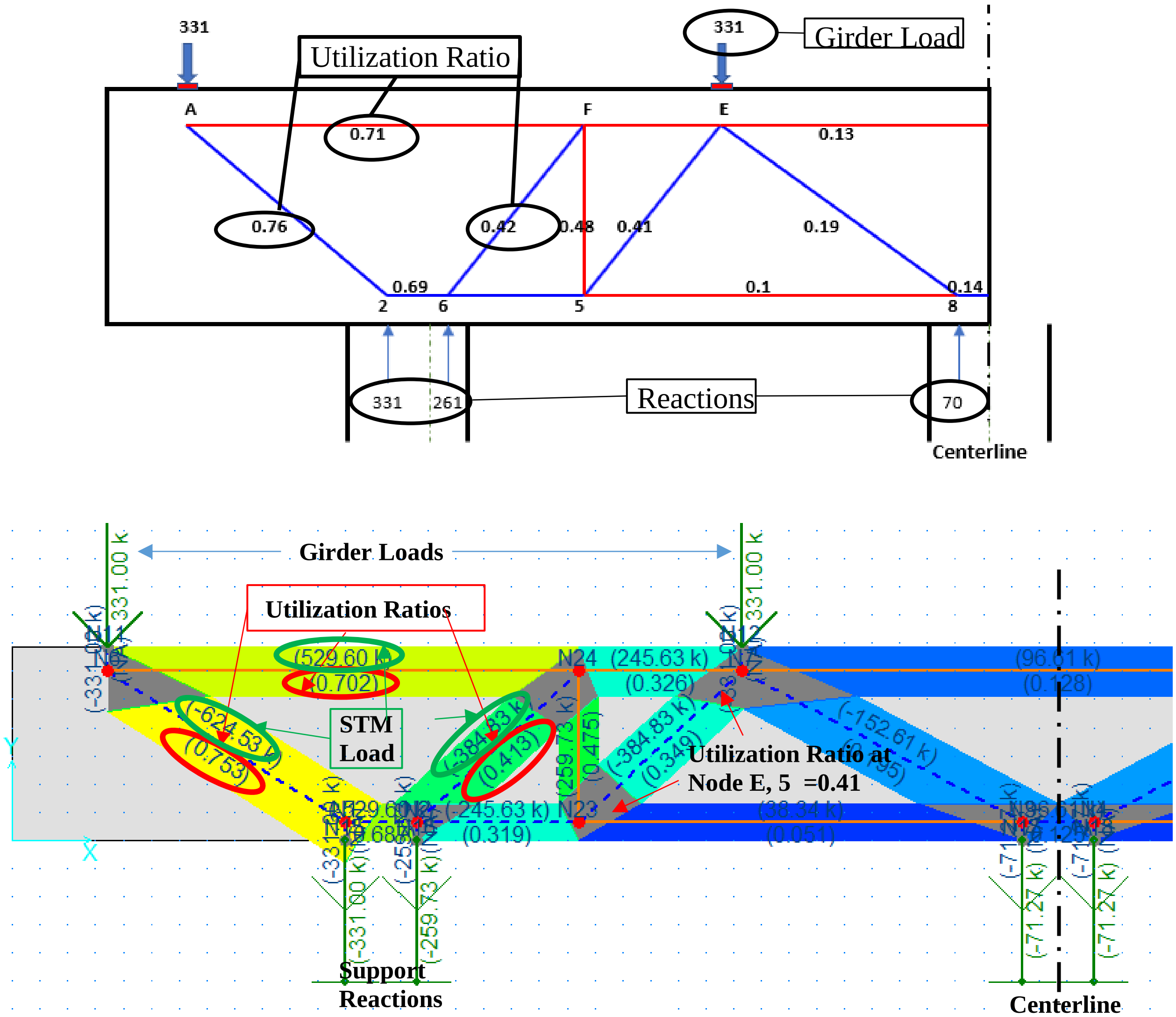


Figure 8 Utilization ratio for a sample bridge from **(a)** STM-CAP **(b)** CAST.

The analysis results of the eight modeled bridge pier caps using STM-CAP and CAST is summarized in **Table 1**, where the utilization ratios are listed for the strut and tie elements. The nodal capacities are considered while calculating the capacities of the strut and tie elements. The maximum utilization ratio of tension ties, horizontal struts, and inclined struts are compared. The largest utilization ratio value governs the cap behavior, with horizontal ties indicating a flexural failure mode, and vertical ties and diagonal struts indicating a shear failure.

Table 1 Bridge pier cap max utilization ratios summary table.

Bridge Name	Pier Cap	Model	STM-CAP	CAST
Bridge 1	Pier 2-Left	Tension Ties	0.71	0.70
		Horizontal Struts	0.69	0.69
		Inclined Struts	0.76	0.75
Bridge 2	Pier 2-Left	Tension Ties	1.02	1.00
		Horizontal Struts	0.83	0.80
		Inclined Struts	0.35	0.34
Bridge 3	North pier cap	Tension Ties	0.51	0.51
		Horizontal Struts	0.35	0.35
		Inclined Struts	0.75	0.74
Bridge 4	Any	Tension Ties	0.50	0.50
		Horizontal Struts	0.32	0.31
		Inclined Struts	0.54	0.54
Bridge 5	Any	Tension Ties	0.47	0.47
		Horizontal Struts	0.32	0.31
		Inclined Struts	0.78	0.78
Bridge 6	Pier 2-Left	Tension Ties	0.37	0.37
		Horizontal Struts	0.52	0.52
		Inclined Struts	0.57	0.57
Bridge 7	Southbound-Left	Tension Ties	0.33	0.34
		Horizontal Struts	0.25	0.25
		Inclined Struts	0.39	0.39
Bridge 8	Southbound-Right	Tension Ties	0.40	0.40
		Horizontal Struts	0.34	0.30
		Inclined Struts	0.48	0.48

CAST verifies the results from the STM-CAP for the eight pier caps modeled and proves its validity for the application of the analysis of pier caps. The utilization ratios compared are essentially equivalent for each of the pier caps. In those exhibiting slight discrepancies, the utilization ratios of the STM-CAP are more accurate than that of CAST verified by hand-calculations.

4.3 Nonlinear Finite Element Modeling using Program VecTor2

VecTor2 was used for the nonlinear finite element modeling of the pier cap. VecTor2 is a non-linear finite element analysis program for two-dimensional structures and is based on the Modified Compression Field Theory. AASHTO LRFD recommends the use of either a strut-and-tie or a nonlinear finite element analysis for deep beams. The nonlinear finite element analysis using VecTor2 considers second order material properties such as compression softening, tension stiffening, and tension splitting, and provides a complete response simulation of the pier cap. This section compares the results from the nonlinear FEM and the strut and tie method based on

AASHTO LRFD (abbreviated as STM-AASHTO) to assess the behavior of the pier cap, the failure patterns, and real field simulation.

Five of the pier caps compared with CAST were also modeled using the nonlinear Finite Element Method (FEM). The crack patterns and stress distributions of the concrete and reinforcement at failure and factored loads were presented. The nonlinear FEM calculated the maximum capacities for the pier caps. The optimized results from STM-AASHTO truss model was used for the comparison. The comparison of the STM-AASHTO results with the stress distribution from the nonlinear FEM was performed based on utilization ratio (the ratio of the stresses at the factored loads divided by the strength of the material). The utilization ratios were calculated and compared to those from the STM-AASHTO for the concrete, main rebar components and for any vertical ties. In addition, the nonlinear load-displacement responses were used to obtain the global capacity of the pier caps.

The maximum utilization ratio of tension ties, horizontal struts, and inclined struts are summarized in **Table 5-1** from STM-AASHTO and nonlinear FEM. The utilization ratios from the nonlinear FEM are 40%, on average, of those from STM-AASHTO. The governing behavior and the mode of failure match for the pier caps. The maximum utilization ratio, which governed the failure, is found in the same member for most of the cases.

In Bridge 2*, the nonlinear FEM determined the failure mode to be the crushing of the concrete caused by shear, which occurred after the yielding of the tensile reinforcement. At the crushing failure, the beam carried twice the load it resisted at the yield of the reinforcement due to significant re-distribution of forces. The STM, on the other hand terminates the analysis at the first yielding of the reinforcement.

Table 2 Utilization ratios summary table from STM-AASHTO & Nonlinear FEM.

Bridge Name	**Pier Cap**	**Model**	**Utilization ratios**		**Nonlinear FEM/ STM-AASHTO**
			STM-AASHTO	**Nonlinear FEM**	
Bridge 1	Pier 2-Left	Tension Ties	0.71	0.37	0.52
		Horizontal Struts	0.69	0.39	0.57
		Inclined Struts	0.49	0.39	0.80
Bridge 2*	Pier 2-Left	Governing Member	1.02	0.15	0.15
Bridge 3	North pier cap	Tension Ties	0.51	0.15	0.29
		Horizontal Struts	0.31	0.15	0.48
		Inclined Struts	0.55	0.26	0.47
Bridge 4	Any	Tension Ties	0.48	0.13	0.27
		Horizontal Struts	0.32	0.19	0.59
		Inclined Struts	0.54	0.21	0.39
Bridge 5	Any	Tension Ties	0.34	0.09	0.26
		Horizontal Struts	0.05	0.02	0.20
		Inclined Struts	0.44	0.17	0.39

The utilization ratio vs shear span-to-depth ratios were compared for the different analysis method and are shown in **Figure 9**.

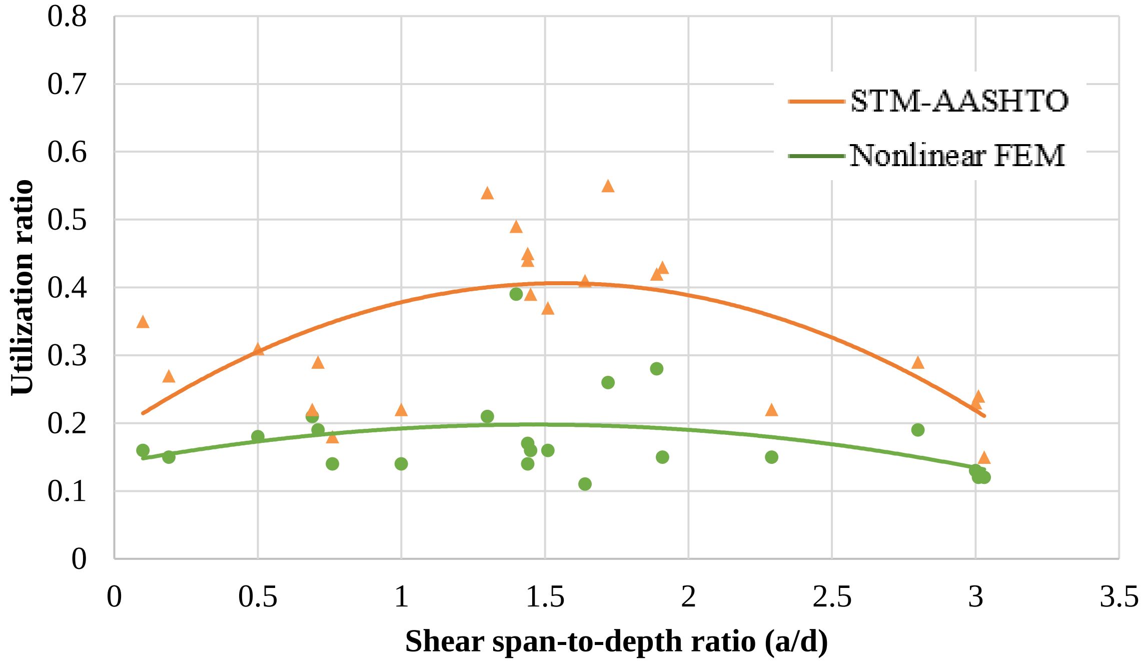


Figure 9 Utilization ratio from STM-AASHTO and Nonlinear FEM vs a/d ratio.

The utilization ratios from the nonlinear FEM and STM-AASHTO displayed a similar trend with a/d ratios. For the same a/d ratio, the utilization ratio was consistently less from the nonlinear FEM than STM-AASHTO. As expected for the deep, as well as, the slender regions, the nonlinear FEM predicts higher shear capacities than those from STM-AASHTO. The utilization ratios from the nonlinear FEM were consistent in almost every region. Three outliers between a/d ratios 1.4 and 2.0 that had a higher utilization ratio in the nonlinear FEM, were from results in the cantilever span of the beam. For a/d ratios between 1.5 and 2.0, the nonlinear FEM predicted lower utilization ratios and up to two times higher shear capacities than STM-AASHTO. With the decrease in a/d ratio, the discrepancy between the nonlinear FEM and STM-AASHTO decreased and both curves converged at a/d ratios less than 0.2.

4.4 Comparison with the Sectional Method

The sectional method is a structural analysis method valid for slender beams (i.e., shear span-to-depth ratios (a/d) >2.0). The sectional method assumes a linear strain distribution throughout a member's depth as per the Euler-Bernoulli hypothesis (Guner, 2008). The sectional method is very simple but not appropriate for deep beams. The Strut-and-Tie Method (STM), which is based on the deep beam theory, does not assume a linear strain distribution, which is more accurate for deep pier caps. Nonlinear finite element analysis methods (e.g., VecTor2) provide complete response simulation with highly accurate results but require significant knowledge and experience to obtain correct results. The strut-and-tie method and the STM-CAP program provide a good compromise between complexity and accuracy. While it is as simple as the sectional method, it provides an accuracy closer to the finite element method. STM is based on the lower bound theorem which is still conservative when compared with nonlinear analysis or experimental tests.

Although the sectional method is not a recommended method, five bridge pier caps were analyzed using the sectional method for comparison with STM-CAP. The shear utilization ratios at critical sections are determined and compared with the sectional method and with STM. For the sectional method, the utilization ratios were calculated as the ratio of the shear force to shear capacity at each critical section (section of interest) using hand calculation. The shear forces are determined using reactions from STM-CAP. The factored sectional shear capacities were calculated based on empirical formulations from AASHTO. For STM, the optimized model from STM-CAP was used to obtain the maximum capacity or minimum possible utilization ratio for each STM member in the pier cap. The utilization ratios of shear by the sectional method was compared with that of the inclined and vertical STM members. The utilization ratios obtained from the sectional method, deep beam theory (STM-CAP) and above nonlinear FEM are plotted in **Figure 10**.

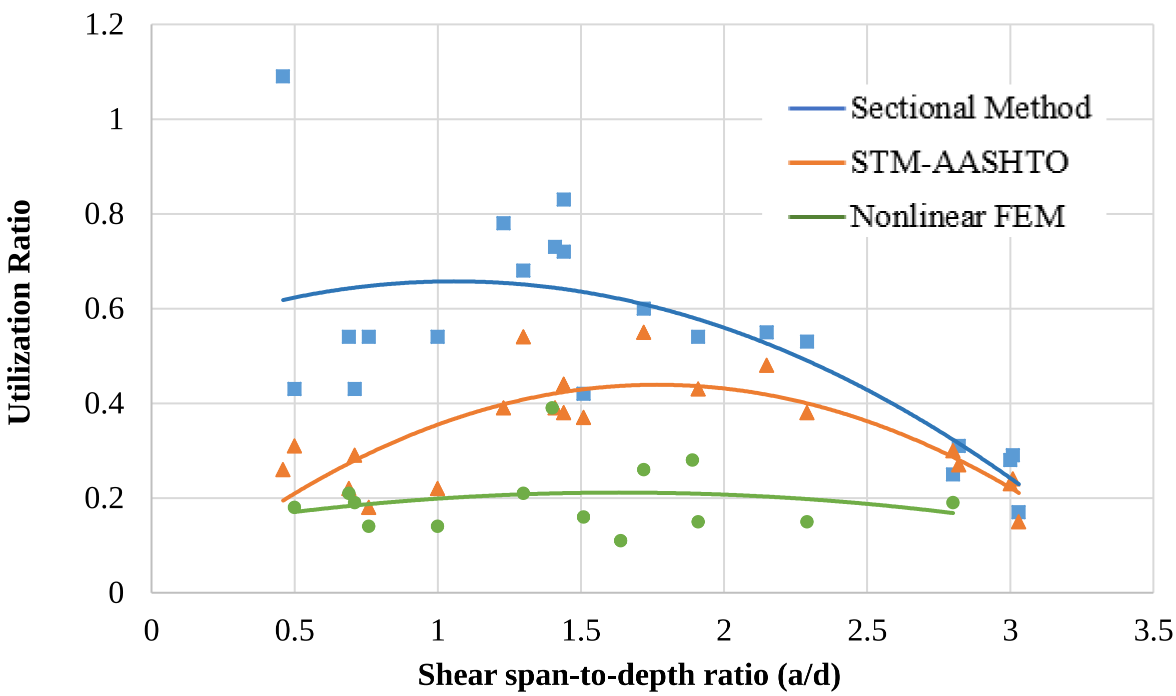


Figure 10 Utilization ratios vs a/d ratios using different analysis technique.

Figure 10 shows the utilization ratio predicted by STM-CAP and the sectional method for 21 regions with the shear span-to-depth ratio (a/d) ranging from 0.45 to 3.0. It is seen that most of the regions in the analyzed pier caps fall within a/d ratios of around 2.0; however, a minority of the regions reached 3.0, clearly indicating that most regions in the pier caps are deep.

The STM-CAP predicted lower utilization ratios and higher shear capacities than the sectional method for almost all cases. For lower a/d ratios (e.g., a/d is around 0.50), the STM-CAP predicted two to three times higher shear capacities. With the increase in a/d ratio, the discrepancy between the predictions by STM-CAP and the sectional method decreased and the results converged approximately at a/d of 2.8 to 3.0. Overall higher shear capacity prediction can be obtained from the STM up to shear span-to-depth ratios of 3.0.

5. Research Findings and Conclusions

This study developed a new analysis tool, STM-CAP (Strut-and-Tie Method for pier CAPs), for the analysis of reinforced concrete multi-column pier caps in order to overcomes the difficulties encountered in the practical applications of the STM (Strut-and-Tie Method). STM-CAP uses Visual Basic Application coding and is embedded into an Excel spreadsheet to eliminate the need to install and learn new software. The Strut and Tie Method, or a nonlinear finite element analysis, is recommended by AASHTO for the analysis of deep pier caps. STM-CAP satisfies this requirement.

Eight bridge pier caps were modeled using STM-CAP. The results were validated using the research-based strut-and-tie software CAST (Computer Aided Sturt-and-Tie). STM-CAP provided identical results to CAST in most cases because both programs work under the same principles of the strut-and-tie conceptualization. In other cases, the STM-CAP provided more accurate utilization ratios than CAST, verified by hand-calculation. In such cases of discrepancy, the difference in the utilization ratios between the two methods was under 5%. One of the reasons for the discrepancies was the geometrical simplifications made in CAST, which used a grid with constant spacing. STM-CAP permitted more accurate input of the bridge geometry (e.g., a girder spacing of 13' and 11.5"). The other reason may involve round off errors. Verification with hand calculations indicated that STM-CAP was more accurate in cases of such discrepancies.

The simulation of the behavior of five pier caps was undertaken using the nonlinear finite element method (FEM) analysis program VecTor2. The behavior of pier caps was found to match STM-AASHTO. The critical members were the same, and the failure patterns matched reasonably well. The members with high utilization ratios from the STM-AASHTO matched the highly stressed members in the nonlinear FEM analysis. The utilization ratios from the nonlinear FEM and STM showed a similar trend with a/d ratios. Nonlinear FEM predicted higher shear capacities, as expected, for the deep as well as the slender regions than the STM-AASHTO. For a/d ratios between 1.5 and 2.0, nonlinear, FEM predicted up to two times larger shear load capacities. As the a/d ratio decreased, the results from the nonlinear FEM and STM-AASHTO converged. The utilization ratios from the nonlinear FEM were determined to be 40% on average of those from STM-AASHTO. Nonlinear FEM provided complete response simulation with highly accurate results but require significant knowledge, analysis time, and experience to obtain correct results. For each cap beam, it took approximately fifteen to twenty hours to create the analysis model, run the simulation, and obtain/understand the analysis results.

The results from the sectional method and the STM-CAP for the same pier caps were compared. The comparisons showed that the sectional method systematically underestimates the shear capacity of deep pier caps. The deeper the pier cap, the higher the discrepancy between calculated shear capacities. For lower a/d ratios (a/d = 0.50), STM-CAP predicted up to 3 times higher shear load capacities. As the a/d ratio increased, the prediction by STM-CAP and the sectional method converged. These STM predictions were still conservative when compared with Nonlinear FEM, as shown in **Figure 10**, because the STM is based on the lower bound theorem. The STM and STM-CAP program provided a good compromise between complexity and accuracy as compared to the sectional method and nonlinear FEM. While it was as simple as the sectional method, it provided an accuracy closer to the finite element method.

6. Recommendations for Implementation of Research Findings

The literature review consistently indicates that the STM estimates the load capacities for deep beams more accurately and less conservatively than the sectional method (i.e., the slender beam theory). Many pier caps qualify as deep beams. STM gives higher and more accurate capacity predictions while still being conservative as compared to a nonlinear finite element analysis. The AASHTO LRFD recommends the use of either a strut-and-tie or a nonlinear finite element model for the analysis and design of deep members. Both methods are more sophisticated and require more effort than the sectional method. Thus, a solution algorithm (thorough a computer program), based on the STM, that can be used in practice for the analysis of the pier caps is required.

The developed program, STM-CAP, follows the AASHTO LRFD 2017. The factored load and factored material resistances are used to perform an LRFD analysis. STM-CAP defines the geometry configuration and detailing of STM elements based on the AASHTO provisions. The tie tensile capacities, strut, and nodal limiting compressive strengths are calculated. It performs the reinforcement development checks, bearing checks, and crack control reinforcement checks as required by the AASHTO LRFD 2017.

STM-CAP is designed for practicing engineers. Its user-friendly interface shows the structure graphically and educates users about the correct use of the STM. The input fields are designed to match the terms used in the engineering plans. A drawing is generated based on the input to minimize the input mistakes. If there are any errors, the user can correct them and re-generate the graphics. STM-CAP generates a graphical output model to show members (color coded), nodes, and utilization ratios for each member. This visualization provides a better understanding of the STM method and analysis results. STM-CAP is designed to encourage engineers and educators to use STM for the analysis of pier caps. STM-CAP permits modeling, analyzing, and obtaining the results within a short period of time. The entire modeling and analysis process can be completed within an hour for a beginning user, and as few as twenty minutes for a user who is experienced with STM-CAP. Consequently, STM-CAP is ready for implementation in practice.

7. Updated AASHTO Formulations

The eighth edition of the AASHTO LRFD code was released during the course of this study. While the results presented in this document are based on the seventh edition of the code, the STM-CAP calculation procedures are fully updated with the provisions contained in the eighth edition. The bridge database discussed in this study was re-analyzed using the latest code and the results are provided in Appendix B. While it is not the scope of this study, the results from both versions of the code were compared.

It was found that the new horizontal strut formulations results in minor capacity changes. In the seventh edition, the capacity of horizontal struts are taken as the minimum capacity of either reinforced struts or the nodal zones, while in the eighth edition the horizontal strut capacities are equal to the sum of these two capacities. Thus, higher capacities are obtained from the horizontal struts where the node capacities were governing in the seventh edition. The new vertical tie formulations (i.e., Section 5.8.2.2 or Figure C5.8.2.2-2), on the other hand, result in a decrease in the tie capacities due to the new provision requiring 25° reduction from the both ends of the shear spans (thus intersecting a smaller number of ties; compare Appendix A and B). The new inclined strut formulations result in higher capacities in most of the cases (compare Appendix A and B) under the same model conditions (same strut angles with no vertical ties). In addition, the new formulations (i.e., Section 5.8.2.5.3a) significantly reduce the strut capacities if the beam does not contain the minimum crack control reinforcement (compare Appendix A and B). It was found that the new horizontal tie capacities are the same as those from the seventh edition. The final version of the STM-CAP program incorporates the updated formulations and will account for these influences.

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9. Appendix A

STM-CAP Solved Examples (AASHTO LRFD 2014)

BRIDGE PIER CAP 1

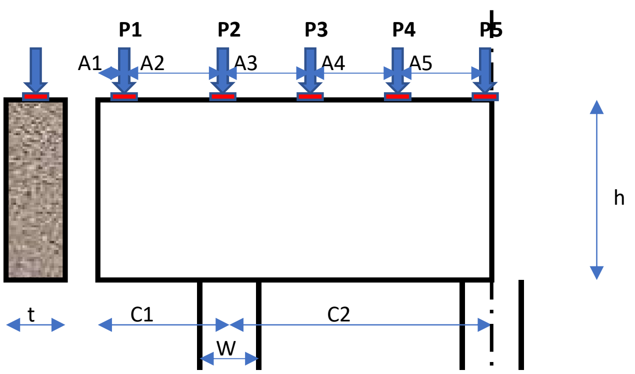
Analysis Input

Bridge Details:

Bridge Name:	Bridge 1	Pier Number:	Pier 2-Left
SFN Number:	570XXXX	Designer:	XXXX
PID No.:	77XXX	Date:	XXXX

1. Total Number of Columns (Piers)	3

☐ Unsymmetrical



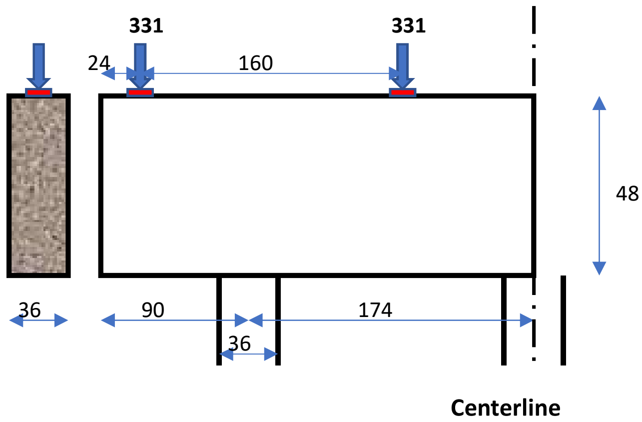
Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	7 ft	6 in	**90 in**
Distance from center of first column to center of second column (C2)	14 ft	6 in	**174 in**
Column width (W)	36 in	Square	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	0 in	**24 in**
Spacing between the girders	13 ft	4 in	**160 in**
Factored Load	331 k		

Factored Load		***Distance***			
P1	331 k	2 ft	0.0 in	**24.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	331 k	13 ft	4.0 in	**160.0 in**	A3
P4	0 k	0 ft	0.0 in	**0.0 in**	A4
P5	0 k	0 ft	0.0 in	**0.0 in**	A5

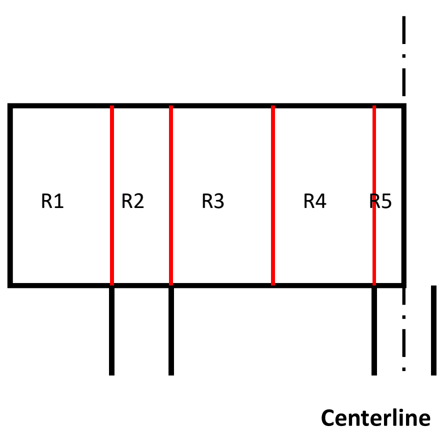


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	60.33 in	1.40	Deep Region
R2	0.00 in	0.00	Zero Region
R3	81.67 in	1.89	Deep Region
R4	71.00 in	1.64	Deep Region
R5	0.00 in	0.00	Zero Region

This pier cap is deep.
Please continue with Section 7.

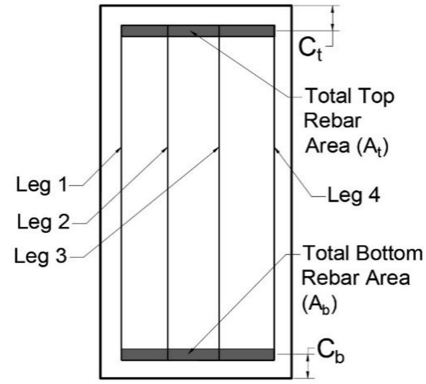
7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



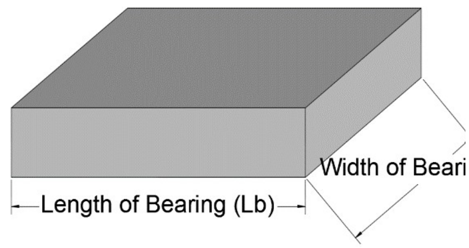
9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	Top Steel (in^2, in)		Bottom Steel (in^2, in)	
	Total Area (A_t)	Centroid (C_t)	Total Area (A_b)	Centroid (C_b)
R1	13.97	6	7	4.5
R2	13.97	6	7	4.5
R3	13.97	6	7	4.5
R4	13.97	6	7	4.5
R5	13.97	6	7	4.5



9B. Transverse Reinforcement		
Region	No. of Legs	Stirrup Spacing
R1	4	5 in
R2	0	0 in
R3	4	10 in
R4	2	12 in
R5	0	0 in

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	13.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in



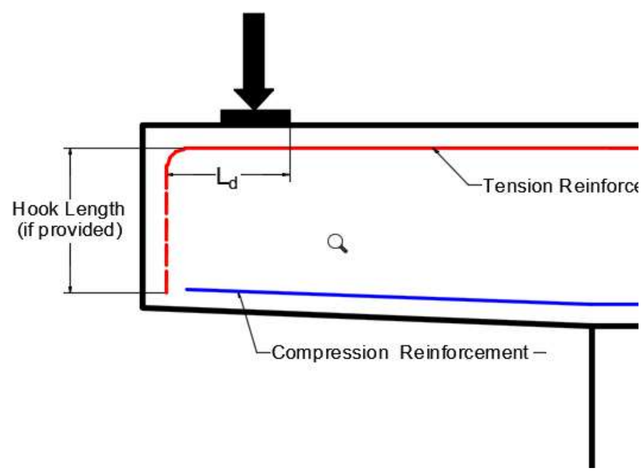
11. Reinforcement Development

Horizontal length available (L_d)	33 in

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.27 in
Enter the length of the hook provided:	30 in
Basic development length	24 in

It qualifies for 90° hook.

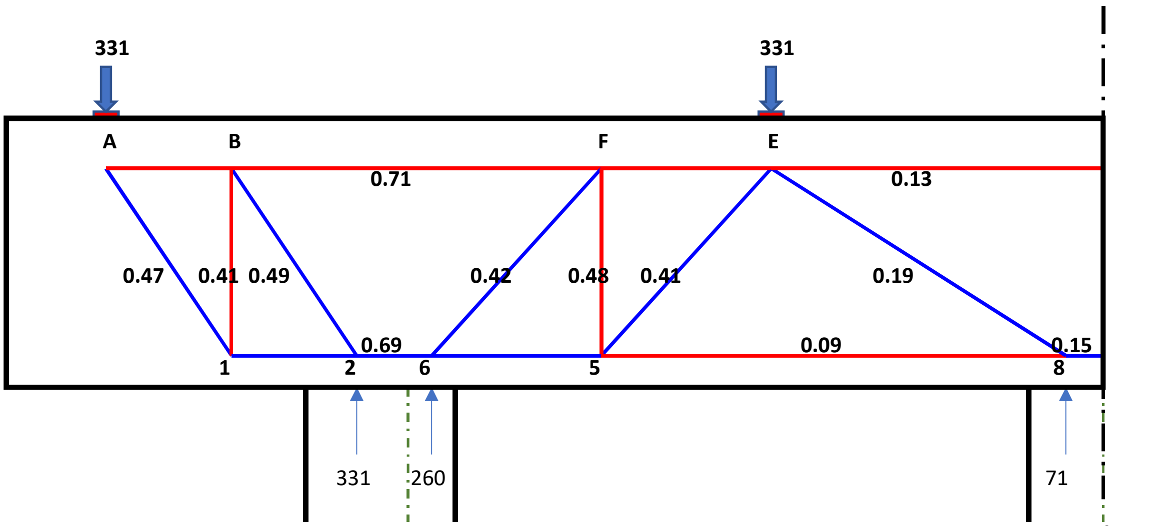
Modification Factor		
1. Are bars epoxy coated?	Yes	1.2
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	1



Required development length	29 in
Available development length (L_d)	33 in

Reinforcement Capacity Multiplier:	1.00

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here

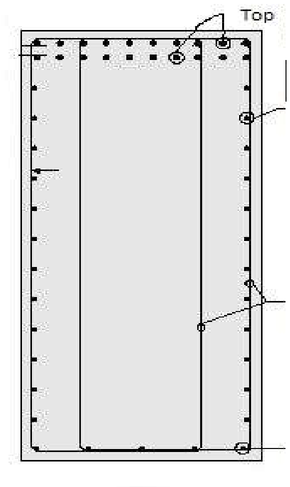
Option	Member Code	Load (k)	Capacity (k)	Utilization Ratio	Result
	B-F	533	754	0.71	PASS
	E-K	101	754	0.13	PASS
	2-6	-533	-771	0.69	PASS
	5-8	34	378	0.09	PASS
	8-12	-101	-680	0.15	PASS
	B-1	331	808	0.41	PASS
	F-5	260	547	0.48	PASS
	H-7	-	-	0.00	-
1	A-1	-425	-896	0.47	PASS
	B-2	-425	-868	0.49	PASS
1	F-6	-384	-923	0.42	PASS
	E-5	-384	-937	0.41	PASS
0	E-8	-152	-780	0.19	PASS

Bearing Areas Nodes at ⇉

Node	Load (k)	Capacity (k)	Utilization Ratio	Result
A	331	573	0.58	PASS
E	331	497	0.67	PASS
2	331	1727	0.19	PASS
6	260	1357	0.19	PASS
8	71	1361	0.05	PASS

14. Informational Check: Min Horizontal Crack Control Reinforcement

				Code Required Min skin reinforcement	0.30%
Region	***Area of the Crack Control Rebar (in^2)***	***Spacing of Crack Control Rebar (in)***	***No of layers of Crack Control Rebars***	***Spacing between skin bars***	***Crack Control Reinforcement***
Region 1	0.31	8.0	2	Good	0.22%
Region 2	0.31	8.0	2	Good	0.22%
Region 3	0.31	8.0	2	Good	0.22%
Region 4	0.31	8.0	2	Good	0.22%
Region 5	0.31	8.0	2	Good	0.22%



BRIDGE PIER CAP 2

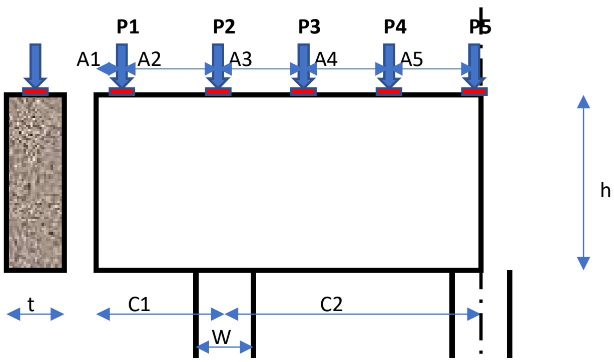
Analysis Input

Bridge Details:

Bridge Name:	Bridge 2	Pier Number:	Pier 2
SFN Number:	570XXXX	Designer:	XXXX
PID No.:	77XXX	Date:	XXXX

1. Total Number of Columns (Piers)	3

☐ Unsymmetrical



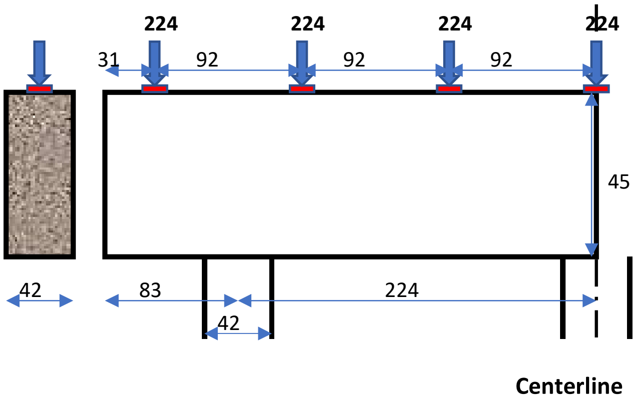
Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	6 ft	11 in	**83 in**
Distance from center of first column to center of second column (C2)	18 ft	8 in	**224 in**
Column width (W)	42 in	**Circular**	
Depth of pier cap (h)	45 in		
Thickness of pier cap (t)	42 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	7 in	**31 in**
Spacing between the girders	7 ft	8 in	**92 in**
Factored Load	224 k		

Factored Load		***Distance***			
P1	224 k	2 ft	7.0 in	**31.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	224 k	7 ft	8.0 in	**92.0 in**	A3
P4	224 k	7 ft	8.0 in	**92.0 in**	A4
P5	224 k	7 ft	8.0 in	**92.0 in**	A5

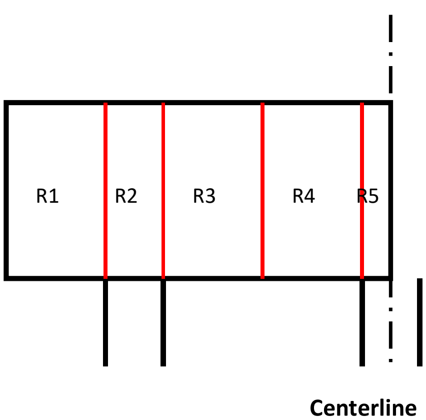


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	**40.41 in**	**1.00**	**Deep Region**
R2	**0.00 in**	**0.00**	**Zero Region**
R3	**30.59 in**	**0.76**	**Deep Region**
R4	**77.36 in**	**1.91**	**Deep Region**
R5	**4.14 in**	**0.10**	**Deep Region**

This pier cap is deep.
Please continue with Section 7.

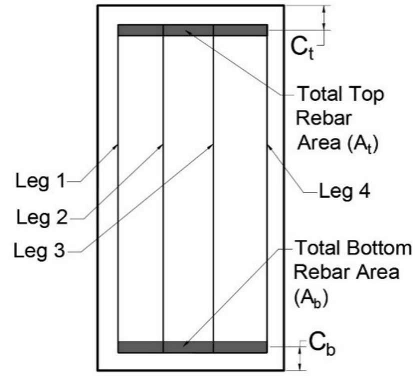
7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



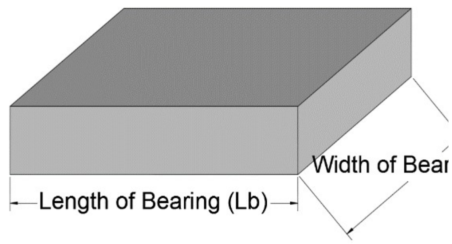
9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	**Top Steel (in^2, in)**		**Bottom Steel (in^2, in)**	
	Total Area (A_t)	**Centroid (C_t)**	**Total Area (A_b)**	**Centroid (C_b)**
R1	9.46	4.45	8	3.15
R2	9.46	4.45	8	3.15
R3	9.46	4.45	8	3.15
R4	9.46	4.45	8	3.15
R5	9.46	4.45	8	3.15



9B. Transverse Reinforcement		
Region	**No. of Legs**	**Stirrup Spacing**
R1	4	10 in
R2	4	10 in
R3	4	10 in
R4	4	10 in
R5	4	10 in

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	20.0 in
Base plate width perpendicular to the pier cap (W_b)	13.0 in



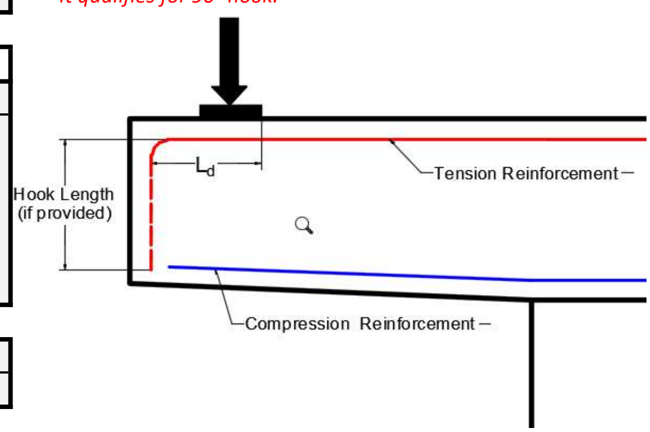
11. Reinforcement Development

Horizontal length available (L_d)	**41 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.27 in
Enter the length of the hook provided:	30 in
Basic development length	**24 in**

It qualifies for 90° hook.

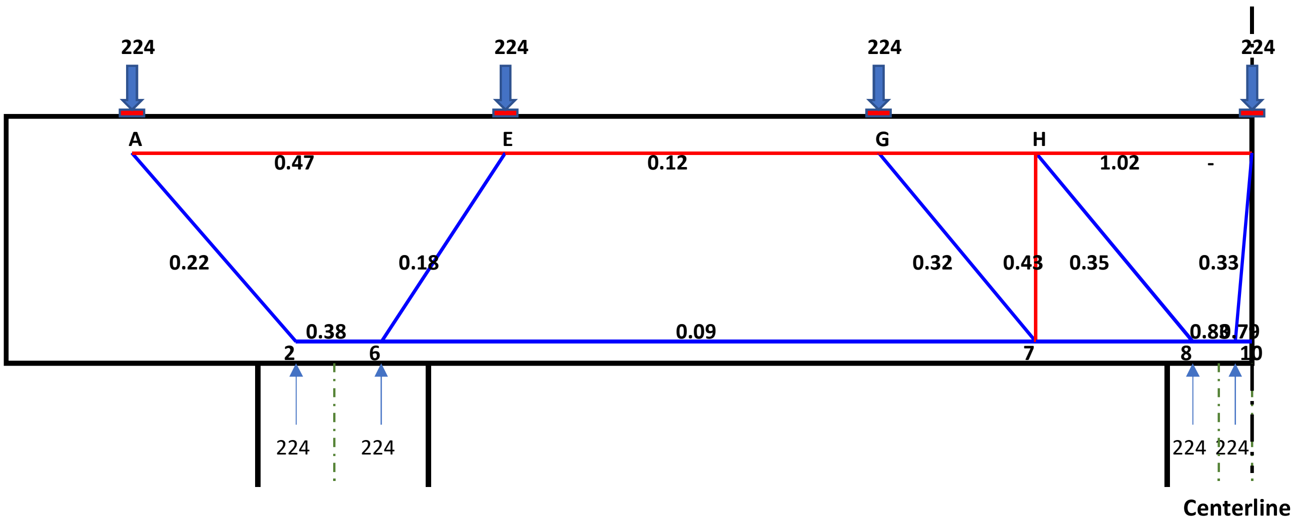
Modification Factor		
1. Are bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**



Required development length	**29 in**
Available development length (L_d)	**41 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

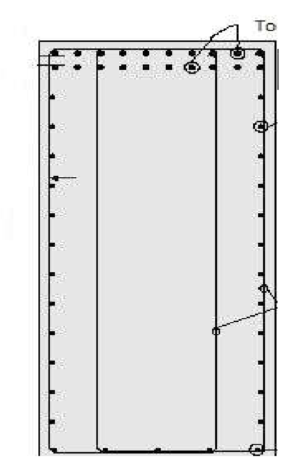
13. Strut and Tie Output Summary

STM Members

	Summary				
	Member Code	***Load (k)***	***Capacity (k)***	***Utilization Ratio***	***Result***
	A-E	242	511	0.47	PASS
	E-G	59	511	0.12	PASS
	H-I	522	511	1.02	Flexure Overloaded
	2-6	-242	-630	0.38	PASS
	6-7	-59	-630	0.09	PASS
	8-10	-522	-630	0.83	PASS
	10-12	-497	-630	0.79	PASS
Input 0 for "Do not use Tie"	B-1	-	-	0.00	-
Input 1 for "Use Tie"	F-5	-	-	0.00	-
Input Your Option Down Here	H-7	224	518	0.43	PASS
↓↓↓↓↓↓↓	J-9	-	-	0.00	-
0	A-2	-330	-1506	0.22	PASS
0	E-6	-289	-1614	0.18	PASS
1	G-7	-322	-1022	0.32	PASS
	H-8	-322	-933	0.35	PASS
0	I-10	-225	-682	0.33	PASS
Bearing Areas Nodes at ⇉	A	224	546	0.41	PASS
	E	224	473	0.47	PASS
	G	224	473	0.47	PASS
	I	224	473	0.47	PASS
	2	224	1649	0.14	PASS
	6	224	1649	0.14	PASS
	8	224	824	0.27	PASS
	10	224	824	0.27	PASS

14. Informational Check: Min Horizontal Crack Control Reinforcement

				Code Required Min skin reinforcement	0.30%
Region	***Area of the Crack Control Rebar (in ^{2})***	***Spacing of Crack Control Rebar (in)***	***No of layers of Crack Control Rebars***	***Spacing between skin bars***	***Crack Control Reinforcement***
Region 1	0.31	8.0	2	Good	0.18%
Region 2	0.31	8.0	2	Good	0.18%
Region 3	0.31	8.0	2	Good	0.18%
Region 4	0.31	8.0	2	Good	0.18%
Region 5	0.31	8.0	2	Good	0.18%



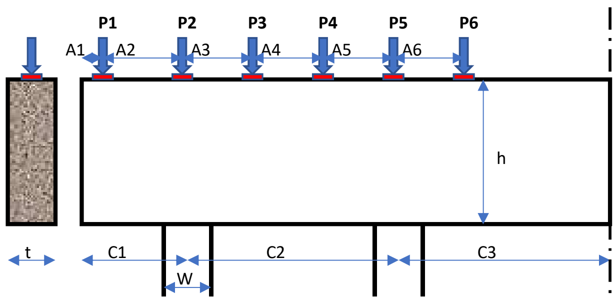
BRIDGE PIER CAP 3

Analysis Input

Bridge Details:

Bridge Name:	Bridge 3	Pier Number:	North Pier
SFN Number:	570XXXX	Designer:	XXXX
PID No.:	77XXX	Date:	XXXX

1. Total Number of Columns (Piers)	4	Unsymmetrical

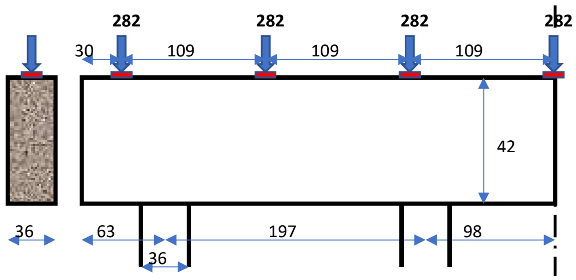


Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	5 ft	3 in	63 in
Distance from center of first column to center of second column (C2)	16 ft	5 in	197 in
Distance from center of second column to centerline of pier cap (C3)	8 ft	2 in	
Column width (W)	36 in	Circular	
Depth of pier cap (h)	42 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	6 in	30 in
Spacing between the girders	9 ft	1 in	109 in
Factored Load	282 k		

Factored Load		***Distance***			
P1	282 k	2 ft	6.0 in	30.0 in	A1
P2	0 k	0 ft	0.0 in	0.0 in	A2
P3	282 k	9 ft	1.0 in	109.0 in	A3
P4	0 k	0 ft	0.0 in	0.0 in	A4
P5	282 k	9 ft	1.0 in	109.0 in	A5
P6	282 k	9 ft	1.0 in	109.0 in	A6



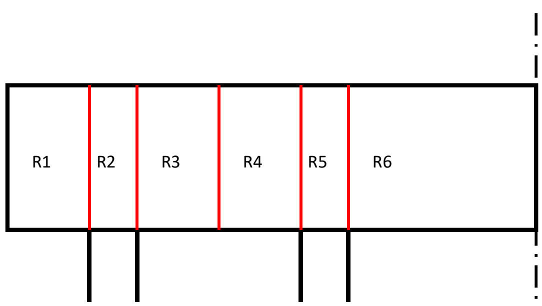
Centerline

6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	**26.15 in**	**0.69**	**Deep Region**
R2	**0.00 in**	**0.00**	**Zero Region**
R3	**64.85 in**	**1.72**	**Deep Region**
R4	**105.91 in**	**2.80**	**Slender Region**
R5	**7.37 in**	**0.19**	**Deep Region**
R6	**87 in**	**2.29**	**Deep Region**

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

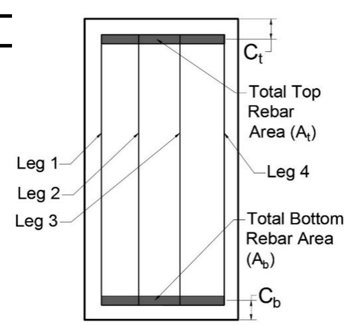
8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



Centerline

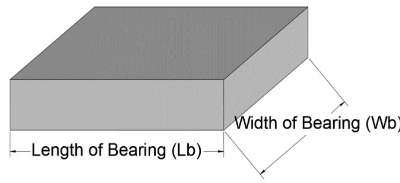
9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in^2, in)***		***Bottom Steel (in^2, in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	8	4.1	8	4.1
R2	8	4.1	8	4.1
R3	8	4.1	8	4.1
R4	8	4.1	8	4.1
R5	8	4.1	8	4.1
R6	8	4.1	8	4.1



9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	4	7 in
R2	0	0 in
R3	4	12 in
R4	4	12 in
R5	0	0 in
R6	4	16 in

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	21.0 in
Base plate width perpendicular to the pier cap (W_b)	13.0 in



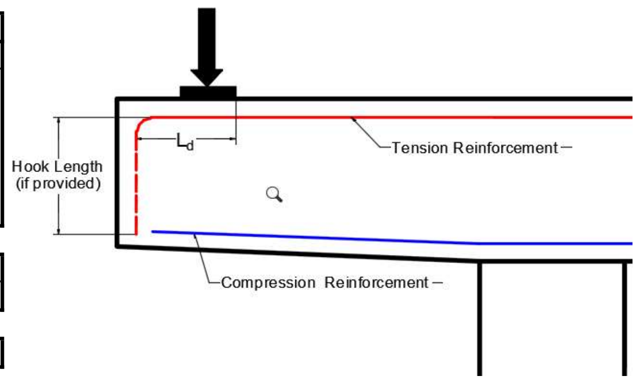
11. Reinforcement Development

Horizontal length available (L_d)	**40 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	**19 in**

It qualifies for 90° hook.

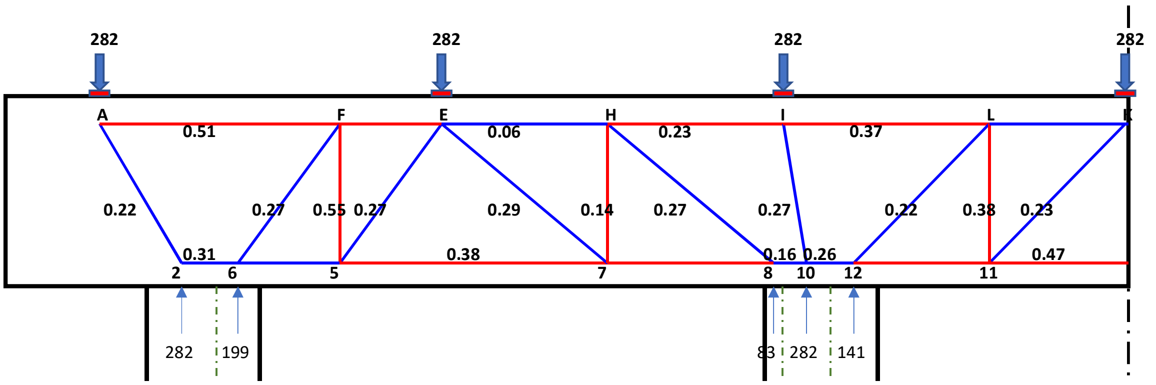
Modification Factor		
1. Are bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**



Required development length	**23 in**
Available development length (L_d)	**40 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

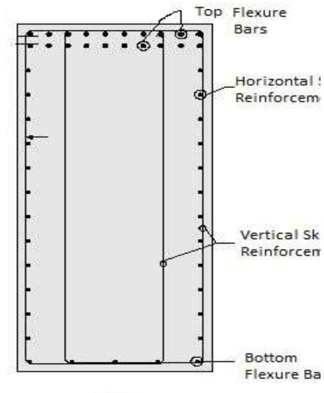
<u>STM Members</u>

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Input	Member Code	Load (k)	Capacity (k)	Utilization Ratio	Result	
	A-F	218	432	0.51	PASS	Top Members
	E-H	-32	-537	0.06	PASS	
	H-I	98	432	0.23	PASS	
	I-L	160	432	0.37	PASS	
	2-6	-218	-703	0.31	PASS	Bottom Members
	5-7	163	432	0.38	PASS	
	8-10	-98	-620	0.16	PASS	
	10-12	-160	-620	0.26	PASS	
	11-14	201	432	0.47	PASS	
	B-1	-	-	0.00	-	Vertical Members
	F-5	199	362	0.55	PASS	
	H-7	83	591	0.14	PASS	
	J-9	-	-	0.00	-	
	L-11	141	374	0.38	PASS	
0	A-2	-357	-1635	0.22	PASS	Inclined Members
1	F-6	-275	-1020	0.27	PASS	
	E-5	-275	-1020	0.27	PASS	
1	E-7	-155	-538	0.29	PASS	
	H-8	-155	-576	0.27	PASS	
0	I-10	-289	-1080	0.27	PASS	
1	L-12	-229	-1032	0.22	PASS	
	K-11	-229	-1010	0.23	PASS	
<u>Bearing Areas</u> Nodes at ⇉	A	282	573	0.49	PASS	1
	E	282	573	0.49	PASS	
	I	282	497	0.57	PASS	
	K	282	650	0.43	PASS	
	2	282	1422	0.20	PASS	2
	6	199	1001	0.20	PASS	
	8	83	352	0.24	PASS	
	10	282	1349	0.21	PASS	
	12	141	595	0.24	PASS	

14. Informational Check: Min Horizontal Crack Control Reinforcement

Code Required Min skin reinforcement					0.30%
Region	***Area of the Crack Control Rebar (in^2)***	***Spacing of Crack Control Rebar (in)***	***No of layers of Crack Control Rebars***	***Spacing between skin bars***	***Crack Control Reinforcement***
Region 1	0.31	8.0	2	Good	0.22%
Region 2	0.31	8.0	2	Good	0.22%
Region 3	0.31	8.0	2	Good	0.22%
Region 4	0.31	8.0	2	Good	0.22%
Region 5	0.31	8.0	2	Good	0.22%
Region 6	0.31	8.0	2	Good	0.22%



BRIDGE PIER CAP 4

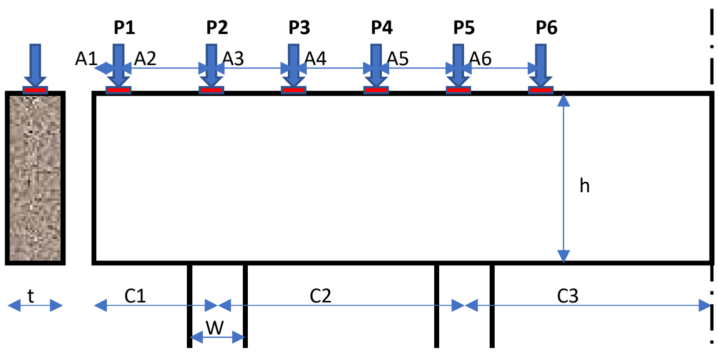
Analysis Input

Bridge Details:

Bridge Name:	Bridge 4	Pier Number:	Left-Unsymmetric
SFN Number:	570XXXX	Designer:	XXXX
PID No.:	77XXX	Date:	XXXX

1. Total Number of Columns (Piers)	4

☐ Unsymmetrical



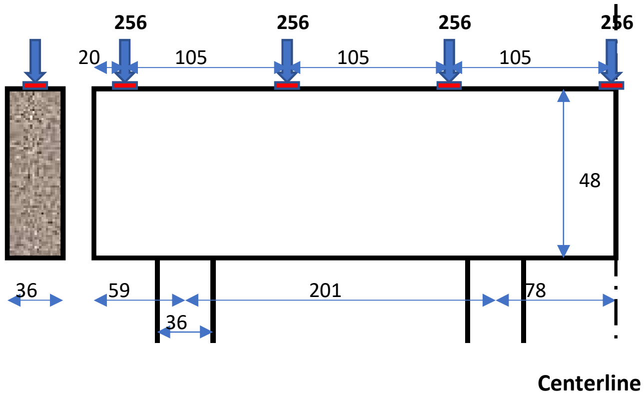
Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	4 ft	11 in	**59 in**
Distance from center of first column to center of second column (C2)	16 ft	9 in	**201 in**
Distance from center of second column to centerline of pier cap (C3)	6 ft	6 in	**78 in**
Column width (W)	36 in	**Circular**	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	1 ft	8 in	**20 in**
Spacing between the girders	8 ft	9 in	**105 in**
Factored Load	256 k		

Factored Load		***Distance***			
P1	256 k	1 ft	8.0 in	**20.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	256 k	8 ft	9.0 in	**105.0 in**	A3
P4	256 k	8 ft	9.0 in	**105.0 in**	A4
P5	0 k	0 ft	0.0 in	**0.0 in**	A5
P6	256 k	8 ft	9.0 in	**105.0 in**	A6

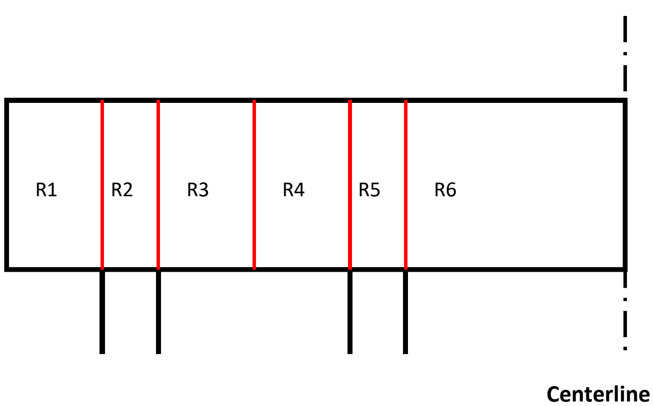


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	**30.89 in**	**0.71**	**Deep Region**
R2	**0.00 in**	**0.00**	**Zero Region**
R3	**56.11 in**	**1.30**	**Deep Region**
R4	**21.74 in**	**0.50**	**Deep Region**
R5	**0.00 in**	**0.00**	**Zero Region**
R6	**65 in**	**1.51**	**Deep Region**

This pier cap is deep.
Please continue with Section 7.

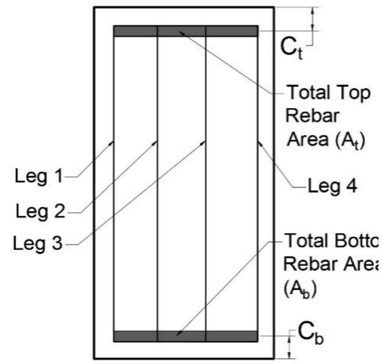
7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	0.79 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



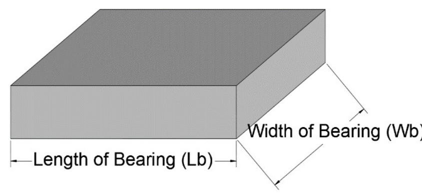
9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in², in)***		***Bottom Steel (in², in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	8	4.5	9	4.2
R2	8	4.5	9	4.2
R3	8	4.5	9	4.2
R4	8	4.5	9	4.2
R5	8	4.5	9	4.2
R6	8	4.5	9	4.2



9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	4	6 in
R2	0	0 in
R3	4	12 in
R4	4	6 in
R5	0	0 in
R6	4	18 in

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	11.5 in
Base plate width perpendicular to the pier cap (W_b)	19.0 in



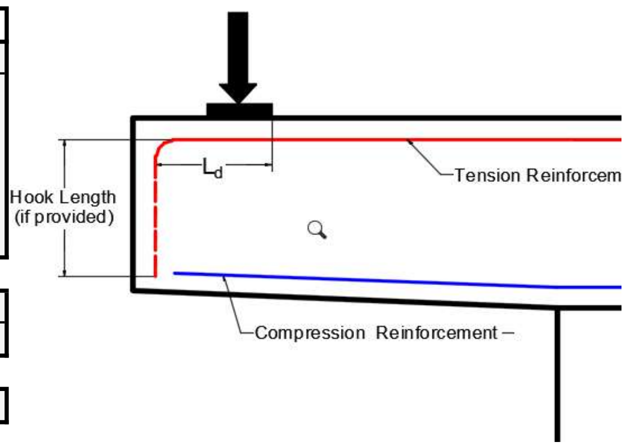
11. Reinforcement Development

Horizontal length available (L_d)	**26 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	**19 in**

It qualifies for 90° hook.

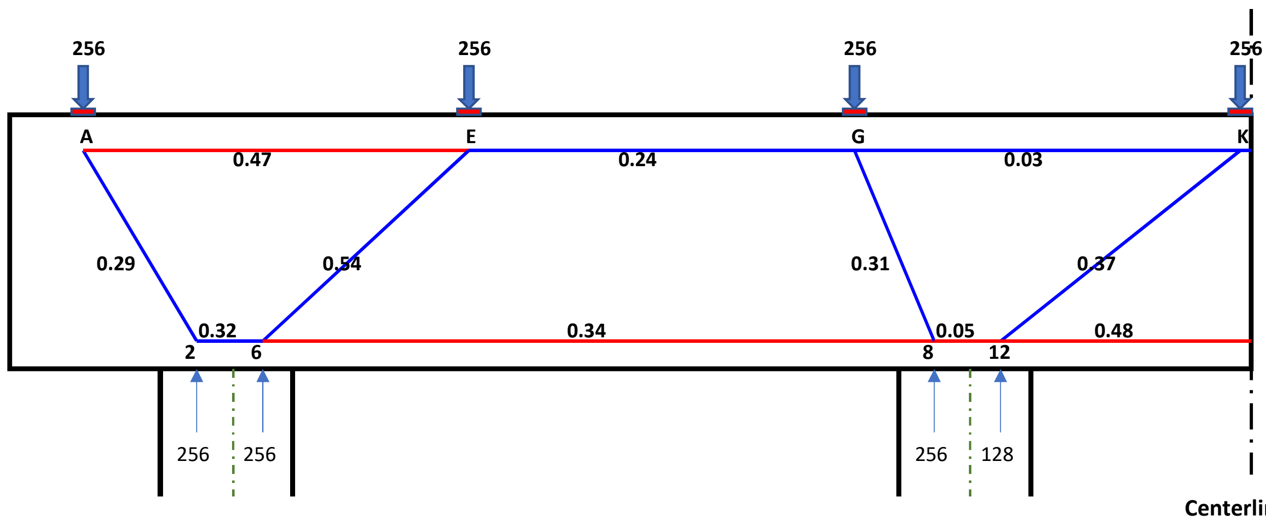
Modification Factor		
1. Are bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**



Required development length	**23 in**
Available development length (L_d)	**26 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Bearing Areas Nodes at ⇉

	Summary				
	Member Code	***Load (k)***	***Capacity (k)***	***Utilization Ratio***	***Result***
	A-E	201	432	0.47	PASS
	E-G	-164	-680	0.24	PASS
	G-K	-23	-771	0.03	PASS
	2-6	-201	-635	0.32	PASS
	6-8	164	486	0.34	PASS
	8-12	23	486	0.05	PASS
	12-14	235	486	0.48	PASS
	B-1	-	-	0.00	-
	F-5	-	-	0.00	-
	H-7	-	-	0.00	-
	L-11	-	-	0.00	-
0	A-2	-326	-1104	0.29	PASS
0	E-6	-446	-820	0.54	PASS
0	G-8	-293	-945	0.31	PASS
0	K-12	-248	-670	0.37	PASS
	A	256	459	0.56	PASS
	E	256	459	0.56	PASS
	G	256	520	0.49	PASS
	K	256	520	0.49	PASS
	2	256	1212	0.21	PASS
	6	256	1069	0.24	PASS
	8	256	1235	0.21	PASS
	12	128	618	0.21	PASS

14. Informational Check: Min Horizontal Crack Control Reinforcement

				Code Required Min skin reinforcement	0.30%
Region	***Area of the Crack Control Rebar (in^2)***	***Spacing of Crack Control Rebar (in)***	***No of layers of Crack Control Rebars***	***Spacing between skin bars***	***Crack Control Reinforcement***
Region 1	0.31	8.0	2	**Good**	**0.22%**
Region 2	0.31	8.0	2	**Good**	**0.22%**
Region 3	0.31	8.0	2	**Good**	**0.22%**
Region 4	0.31	8.0	2	**Good**	**0.22%**
Region 5	0.31	8.0	2	**Good**	**0.22%**
Region 6	0.31	8.0	2	**Good**	**0.22%**

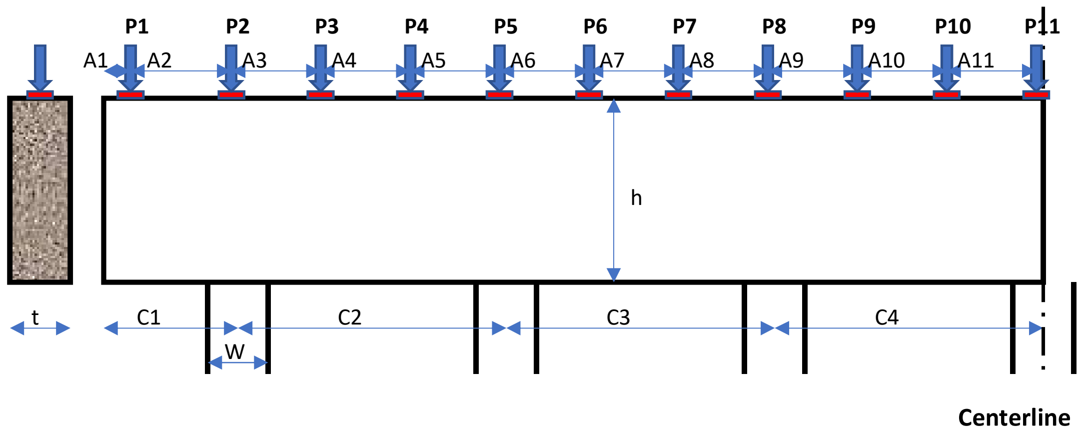
BRIDGE PIER CAP 5

Analysis Input

Bridge Details:

Bridge Name:	Bridge 5		Pier 4
SFN Number:	570XXXX		XXXX
PID No.:	77XXX		XXXX

1. Total Number of Columns (Piers)	7

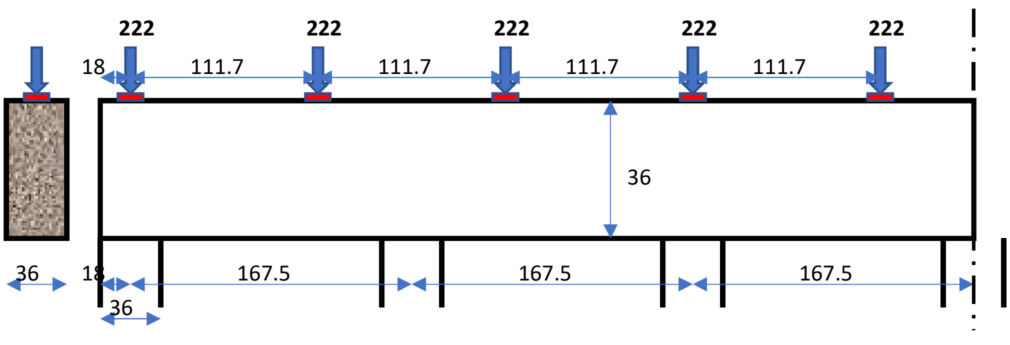


Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	1 ft	6 in	**18 in**
Distance from center of first column to center of second column (C2)	13 ft	12 in	**168 in**
Distance from center of second column to center of third column (C3)	13 ft	12 in	
Distance from center of third column to center of fourth column (C4)	13 ft	12 in	**168 in**
Column width (W)	36 in	**Circular**	
Depth of pier cap (h)	36 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	1 ft	6 in	18 in
Spacing between the girders	9 ft	4 in	112 in
Factored Load	222 k		

Factored Load		*Distance*			
P1	0 k	0 ft	0.0 in	0.0 in	A1
P2	222 k	1 ft	6.0 in	18.0 in	A2
P3	222 k	9 ft	3.7 in	111.7 in	A3
P4	0 k	0 ft	0.0 in	0.0 in	A4
P5	0 k	0 ft	0.0 in	0.0 in	A5
P6	222 k	9 ft	3.7 in	111.7 in	A6
P7	0 k	0 ft	0.0 in	0.0 in	A7
P8	222 k	9 ft	3.7 in	111.7 in	A8
P9	222 k	9 ft	3.7 in	111.7 in	A9
P10	0 k	0 ft	0.0 in	0.0 in	A10
P11	0 k	0 ft	0.0 in	0.0 in	A11

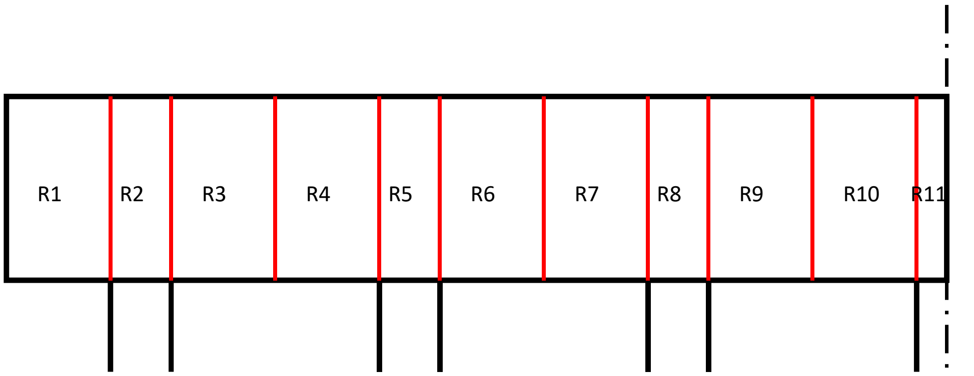


6. Check whether the Pier Cap is Deep			
Region	*Shear span (a)*	*a/d ratio:*	*Result*
R1	0.00 in	0.00	Zero Region
R2	4.50 in	0.14	Deep Region
R3	98.20 in	3.03	Slender Region
R4	46.80 in	1.44	Deep Region
R5	0.00 in	0.00	Zero Region
R6	47 in	1.45	Deep Region
R7	97 in	3.00	Slender Region
R8	0 in	0.00	Deep Region
R9	97 in	3.01	Slender Region
R10	47 in	1.44	Deep Region
R11	0 in	0.00	Zero Region

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	0.79 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

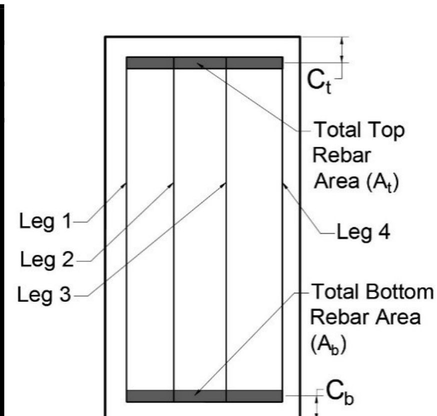
8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



Centerline

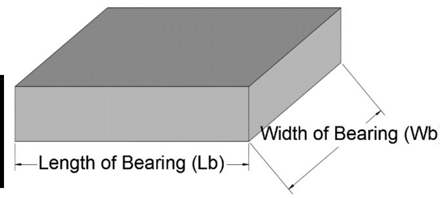
9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in^2, in)***		***Bottom Steel (in^2, in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	7.9	4.2	7.9	4.2
R2	7.9	4.2	7.9	4.2
R3	7.9	4.2	7.9	4.2
R4	7.9	4.2	7.9	4.2
R5	7.9	4.2	7.9	4.2
R6	7.9	4.2	7.9	4.2
R7	7.9	4.2	7.9	4.2
R8	7.9	4.2	7.9	4.2
R9	7.9	4.2	7.9	4.2
R10	7.9	4.2	7.9	4.2
R11	7.9	4.2	7.9	4.2



9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	0	0 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18 in
R7	4	20 in
R8	4	20 in
R9	4	20 in
R10	4	18 in
R11	4	18 in

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	19.0 in
Base plate width perpendicular to the pier cap (W_b)	12.0 in



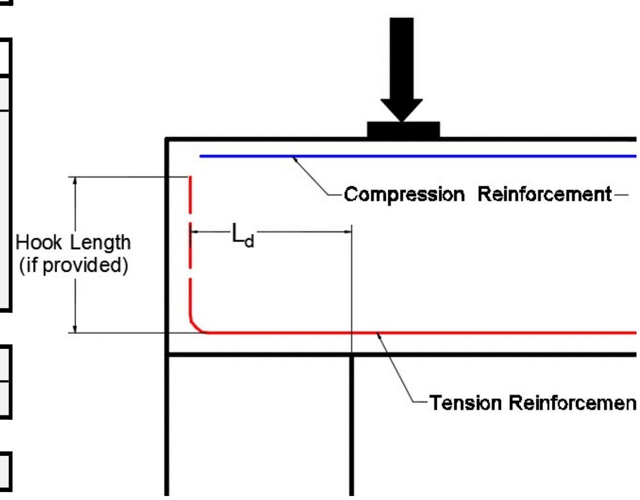
11. Reinforcement Development

Horizontal length available	**25 in**

Bottom Tension Bars	
Enter the Diameter of the Bottom longitudinal bar:	0.79 in
Enter the Length of the hook Provided:	27 in
Basic Development Length	**15 in**

It qualifies for 90° hook.

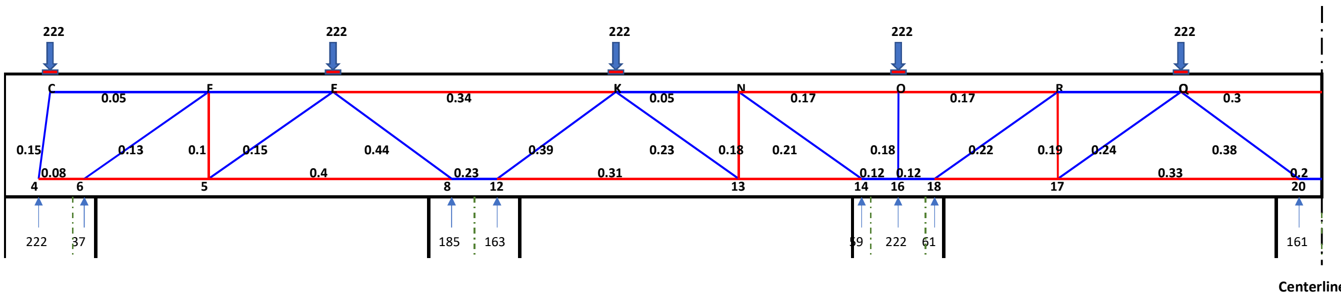
Modification Factor		
1. Are those bars epoxy coated?	No	**1**
2. Is the side cover for No. 11 Bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**



Required development length	**15 in**
Available development length (L_d)	**25 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

	Summary				
	Member Code	***Load (k)***	***Capacity (k)***	***Utilization Ratio***	***Result***
	C-F	-36	-720	0.05	PASS
	E-K	144	427	0.34	PASS
	K-N	-29	-550	0.05	PASS
	N-O	74	427	0.17	PASS
	O-R	73	427	0.17	PASS
	Q-W	130	427	0.30	PASS
	4-6	36	427	0.08	PASS
	5-8	169	427	0.40	PASS
	8-12	-144	-635	0.23	PASS
	12-13	133	427	0.31	PASS
	14-16	-74	-635	0.12	PASS
	16-18	-73	-635	0.12	PASS
	17-20	142	427	0.33	PASS
	20-24	-130	-635	0.20	PASS
1	F-5	37	365	0.10	PASS
0	H-7	-	-	0.00	-
0	L-11	-	-	0.00	-
1	N-13	59	325	0.18	PASS
1	R-17	61	326	0.19	PASS
0	T-19	-	-	0.00	-
	C-4	-225	-1520	0.15	PASS
	F-6	-76	-566	0.13	PASS
	E-5	-76	-515	0.15	PASS
	E-8	-364	-817	0.44	PASS
	K-12	-322	-829	0.39	PASS
	K-13	-119	-521	0.23	PASS
	N-14	-119	-557	0.21	PASS
	O-16	-222	-1247	0.18	PASS
	R-18	-124	-555	0.22	PASS
	Q-17	-124	-514	0.24	PASS
	Q-20	-316	-835	0.38	PASS
	C	222	543	0.41	PASS
	E	222	543	0.41	PASS
	K	222	479	0.46	PASS
	O	222	415	0.53	PASS
	Q	222	479	0.46	PASS
	4	222	1830	0.12	PASS
	6	37	267	0.14	PASS
	8	185	1135	0.16	PASS
	12	163	1003	0.16	PASS
	14	59	368	0.16	PASS
	16	222	1573	0.14	PASS
	18	61	382	0.16	PASS
	20	161	1069	0.15	PASS

14. Informational Check: Min Horizontal Crack Control Reinforcement

Region	Area of the Crack Control Rebar (in^2)	Spacing of Crack Control Rebar (in)	No of layers of Crack Control Rebars	Spacing between skin bars	Crack Control Reinforcement
				Code Required Min skin reinforcement	0.30%
Region 1	0.31	8.0	2	Good	0.22%
Region 2	0.31	8.0	2	Good	0.22%
Region 3	0.31	8.0	2	Good	0.22%
Region 4	0.31	8.0	2	Good	0.22%
Region 5	0.31	8.0	2	Good	0.22%
Region 6	0.31	8.0	2	Good	0.22%
Region 7	0.31	6.5	2	Good	0.26%
Region 8	0.31	6.5	2	Good	0.26%
Region 9	0.31	6.5	2	Good	0.26%
Region 10	0.31	6.5	2	Good	0.26%
Region 11	0.31	6.5	2	Good	0.26%

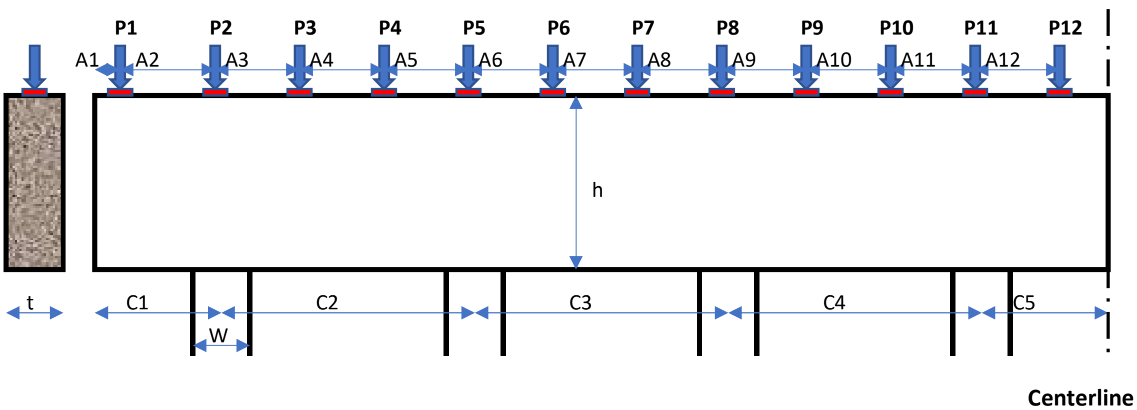
BRIDGE PIER CAP 6

Analysis Input

Bridge Details:

Bridge Name:	Bridge 6	Pier Number:	Pier-2 Left
SFN Number:	570XXXX	Designer:	XXXX
PID No.:	77XXX	Date:	XXXX

1. Total Number of Columns (Piers)	8	☑ Unsymmetrical

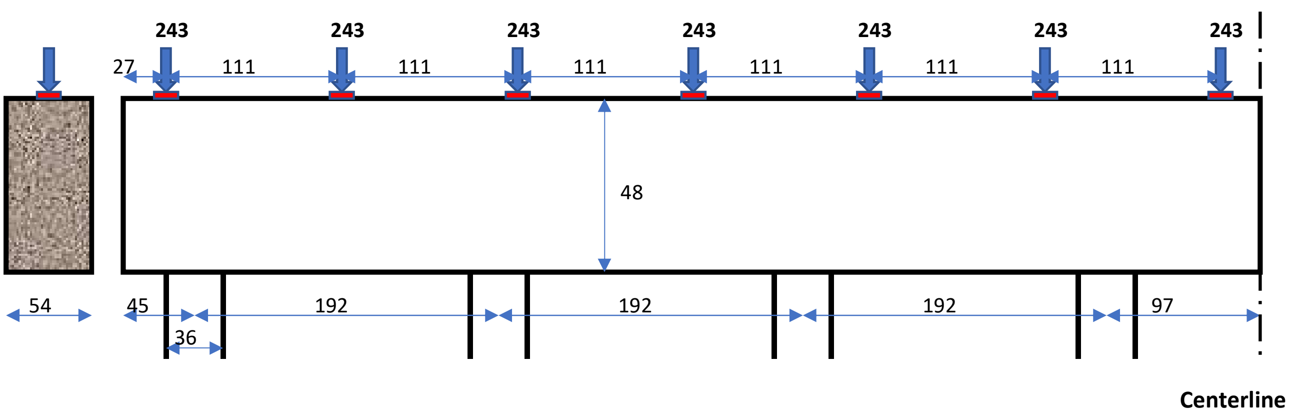


Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	3 ft	9 in	**45 in**
Distance from center of first column to center of second column (C2)	16 ft	0 in	**192 in**
Distance from center of second column to center of third column (C3)	16 ft	0 in	**192 in**
Distance from center of third column to center of fourth column (C4)	16 ft	0 in	**192 in**
Distance from center of fourth column to centerline of pier cap (C5)	8 ft	1 in	**97 in**
Column width (W)	36 in	**Circular**	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	54 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	3 in	27 in
Spacing between the girders	9 ft	3 in	111 in
Factored Load	243 k		

Factored Load		*Distance*			
P1	243 k	2 ft	3.0 in	27.0 in	A1
P2	0 k	0 ft	0.0 in	0.0 in	A2
P3	243 k	9 ft	3.0 in	111.0 in	A3
P4	0 k	0 ft	0.0 in	0.0 in	A4
P5	243 k	9 ft	3.0 in	111.0 in	A5
P6	243 k	9 ft	3.0 in	111.0 in	A6
P7	0 k	0 ft	0.0 in	0.0 in	A7
P8	0 k	0 ft	0.0 in	0.0 in	A8
P9	243 k	9 ft	3.0 in	111.0 in	A9
P10	243 k	9 ft	3.0 in	111.0 in	A10
P11	0 k	0 ft	0.0 in	0.0 in	A11
P12	243 k	9 ft	3.0 in	111.0 in	A12

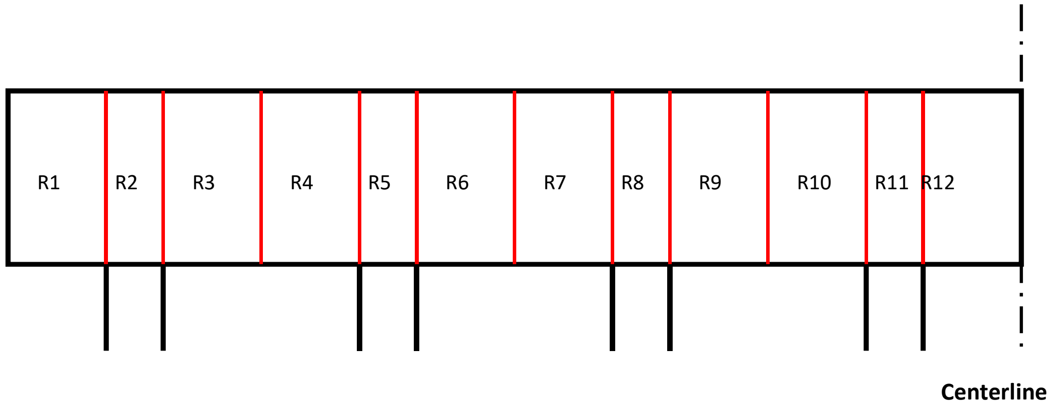


6. Check whether the Pier Cap is Deep			
Region	*Shear span (a)*	*a/d ratio:*	*Result*
R1	11.88 in	0.27	Deep Region
R2	0.00 in	0.00	Zero Region
R3	81.12 in	1.88	Deep Region
R4	85.73 in	1.98	Deep Region
R5	10.78 in	0.25	Deep Region
R6	109 in	2.51	Slender Region
R7	58 in	1.34	Deep Region
R8	0 in	0.00	Zero Region
R9	17 in	0.39	Deep Region
R10	30 in	0.70	Deep Region
R11	0 in	0.00	Zero Region
R12	45 in	1.04	Deep Region

This pier cap is deep.
Please continue with Section 7.

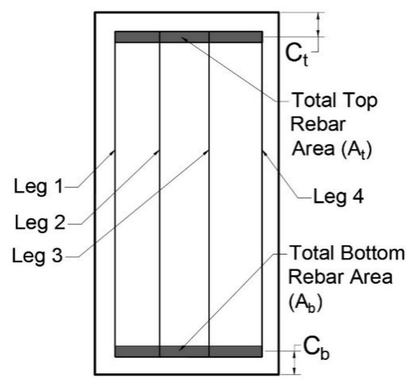
7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	1.27 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



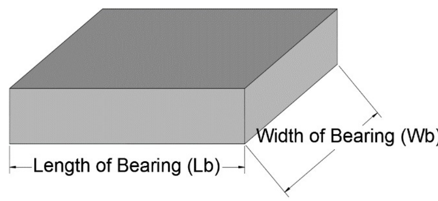
9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in², in)***		***Bottom Steel (in², in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	22.86	5.5	11.43	3
R2	22.86	5.5	11.43	3
R3	22.86	5.5	11.43	3
R4	22.86	5.5	11.43	3
R5	22.86	5.5	11.43	3
R6	22.86	5.5	11.43	3
R7	22.86	5.5	11.43	3
R8	22.86	5.5	11.43	3
R9	22.86	5.5	11.43	3
R10	22.86	5.5	11.43	3
R11	22.86	5.5	11.43	3
R12	22.86	5.5	11.43	3



9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	0	0 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18 in
R7	4	20 in
R8	4	20 in
R9	4	20 in
R10	4	18 in
R11	4	18 in
R12	0	0 in

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	13.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in



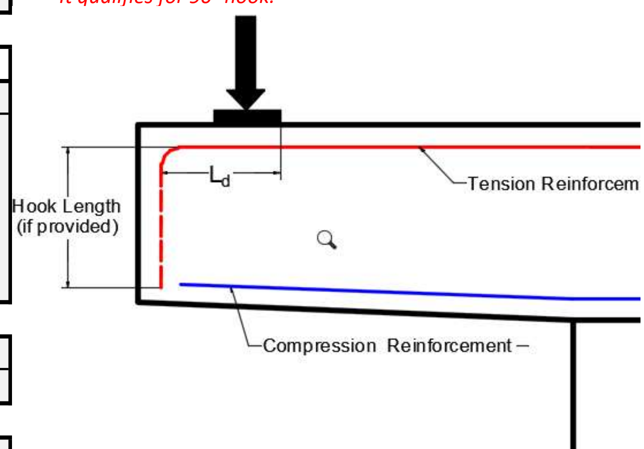
11. Reinforcement Development

Horizontal length available (L_d)	**32 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.27 in
Enter the length of the hook provided:	30 in
Basic development length	**24 in**

It qualifies for 90° hook.

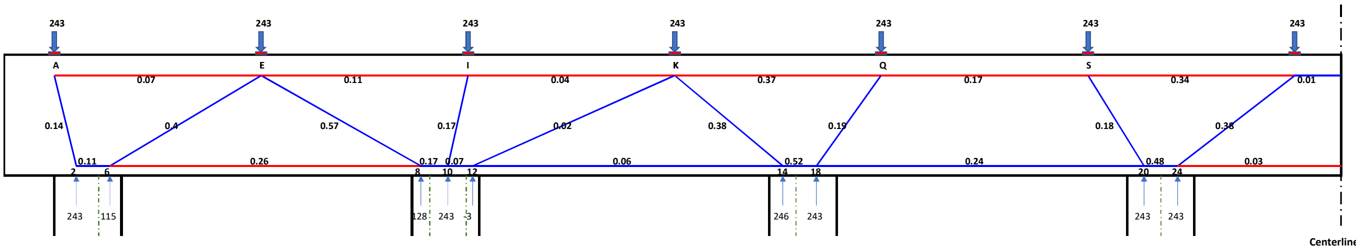
Modification Factor		
1. Are bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**



Required development length	**29 in**
Available development length (L_d)	**32 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Bearing Areas Nodes at ⇉

	Summary				
	Member Code	*Load (k)*	*Capacity (k)*	*Utilization Ratio*	*Result*
	A-E	73	1081	0.07	PASS
	E-I	114	1081	0.11	PASS
	I-K	48	1081	0.04	PASS
	K-Q	401	1081	0.37	PASS
	Q-S	187	1081	0.17	PASS
	S-W	372	1081	0.34	PASS
	W+	-16	-1247	0.01	PASS
	2-6	-73	-680	0.11	PASS
	6-8	164	617	0.26	PASS
	8-10	-114	-680	0.17	PASS
	10-12	-48	-680	0.07	PASS
	12-14	-40	-680	0.06	PASS
	14-18	-401	-771	0.52	PASS
	18-20	-187	-771	0.24	PASS
	20-24	-372	-771	0.48	PASS
	24+	16	617	0.03	PASS
	B-1	-	-	0.00	-
	F-5	-	-	0.00	-
	H-7	-	-	0.00	-
	J-9	-	-	0.00	-
	L-11	-	-	0.00	-
	N-13	-	-	0.00	-
	R-17	-	-	0.00	-
	T-19	-	-	0.00	-
	X-23	-	-	0.00	-
0	A-2	-254	-1771	0.14	PASS
0	E-6	-263	-663	0.40	PASS
0	E-8	-305	-539	0.57	PASS
0	I-10	-252	-1517	0.17	PASS
0	K-12	-8	-351	0.02	PASS
0	K-14	-437	-1141	0.38	PASS
0	Q-18	-324	-1673	0.19	PASS
0	S-20	-305	-1671	0.18	PASS
0	W-24	-457	-1203	0.38	PASS
	A	243	573	0.42	PASS
	E	243	497	0.49	PASS
	I	243	497	0.49	PASS
	K	243	497	0.49	PASS
	Q	243	497	0.49	PASS
	S	243	497	0.49	PASS
	W	243	573	0.42	PASS
	2	243	1644	0.15	PASS
	6	115	688	0.17	PASS
	8	128	743	0.17	PASS
	10	243	1600	0.15	PASS
	12	-3	-16	0.17	PASS
	14	246	1219	0.20	PASS
	18	243	1204	0.20	PASS
	20	243	1212	0.20	PASS
	24	243	1212	0.20	PASS

14. Informational Check: Min Horizontal Crack Control Reinforcement

				Code Required Min skin reinforcement	0.30%
Region	***Area of the Crack Control Rebar (in^2)***	***Spacing of Crack Control Rebar (in)***	***No of layers of Crack Control Rebars***	***Spacing between skin bars***	***Crack Control Reinforcement***
Region 1	0.31	8.0	2	**Good**	**0.14%**
Region 2	0.31	8.0	2	**Good**	**0.14%**
Region 3	0.31	8.0	2	**Good**	**0.14%**
Region 4	0.31	8.0	2	**Good**	**0.14%**
Region 5	0.31	8.0	2	**Good**	**0.14%**
Region 6	0.31	8.0	2	**Good**	**0.14%**
Region 7	0.31	6.5	2	**Good**	**0.18%**
Region 8	0.31	6.5	2	**Good**	**0.18%**
Region 9	0.31	6.5	2	**Good**	**0.18%**
Region 10	0.31	6.5	2	**Good**	**0.18%**
Region 11	0.31	6.5	2	**Good**	**0.18%**
Region 12	0.31	6.5	4	**Good**	**0.35%**

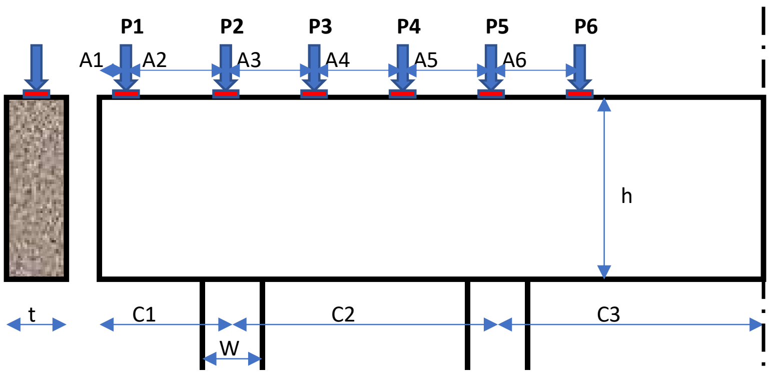
BRIDGE PIER CAP 7

Analysis Input

Bridge Details:

Bridge Name:	Bridge 7		Southbound (Left)
SFN Number:	570XXXX		XXXX
PID No.:	77XXX		XXXX

1. Total Number of Columns (Piers)	4	Unsymmetrical



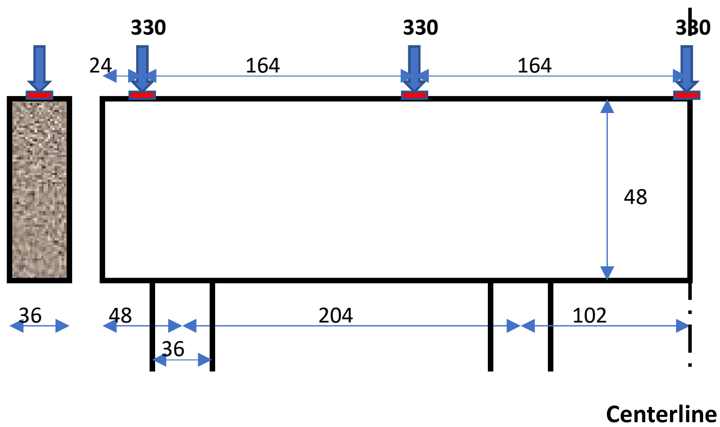
Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	4 ft	0 in	**48 in**
Distance from center of first column to center of second column (C2)	17 ft	0 in	**204 in**
Distance from center of second column to centerline of pier cap (C3)	8 ft	6 in	
Column width (W)	36 in	**Square**	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	0 in	**24 in**
Spacing between the girders	13 ft	8 in	**164 in**
Factored Load	330 k		

Factored Load		***Distance***			
P1	330 k	2 ft	0.0 in	**24.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	330 k	13 ft	8.0 in	**164.0 in**	A3
P4	0 k	0 ft	0.0 in	**0.0 in**	A4
P5	0 k	0 ft	0.0 in	**0.0 in**	A5
P6	330 k	13 ft	8.0 in	**164.0 in**	A6

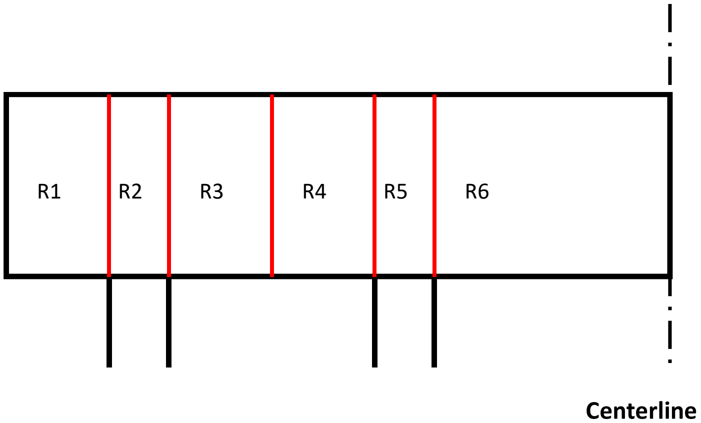


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	19.70 in	0.46	Deep Region
R2	0.00 in	0.00	Zero Region
R3	126.30 in	2.92	Slender Region
R4	53.33 in	1.23	Deep Region
R5	0.00 in	0.00	Zero Region
R6	93 in	2.15	Deep Region

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

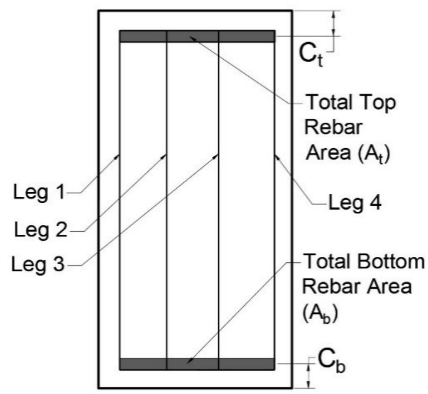
8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



9. Reinforcement Details

9A. Longitudinal Reinforcement

Region	Top Steel (in^2, in)		Bottom Steel (in^2, in)	
	Total Area (A_t)	Centroid (C_t)	Total Area (A_b)	Centroid (C_b)
R1	12	5	12	5
R2	12	5	12	5
R3	12	5	12	5
R4	12	5	12	5
R5	12	5	12	5
R6	12	5	12	5

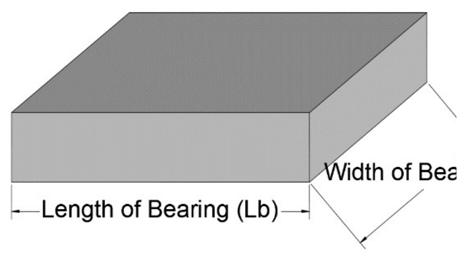


9B. Transverse Reinforcement

Region	No. of Legs	Stirrup Spacing
R1	4	18 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18 in

10. Base Plate Dimensions

Base plate length parallel to the pier cap (L_b)	16.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in

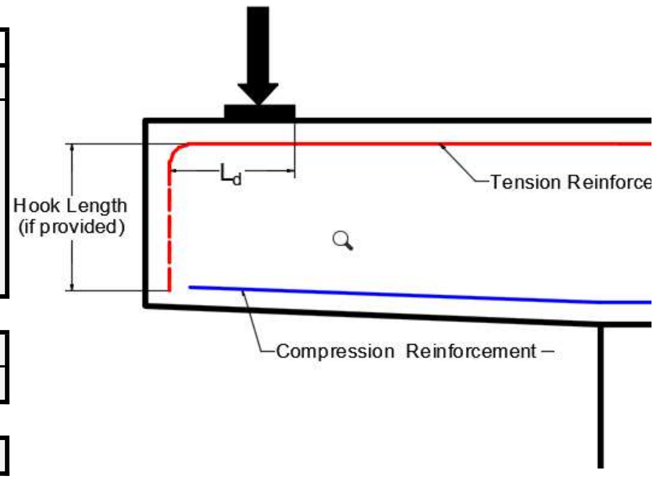


11. Reinforcement Development

Horizontal length available (L_d)	31 in

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	19 in

It qualifies for 90° hook.

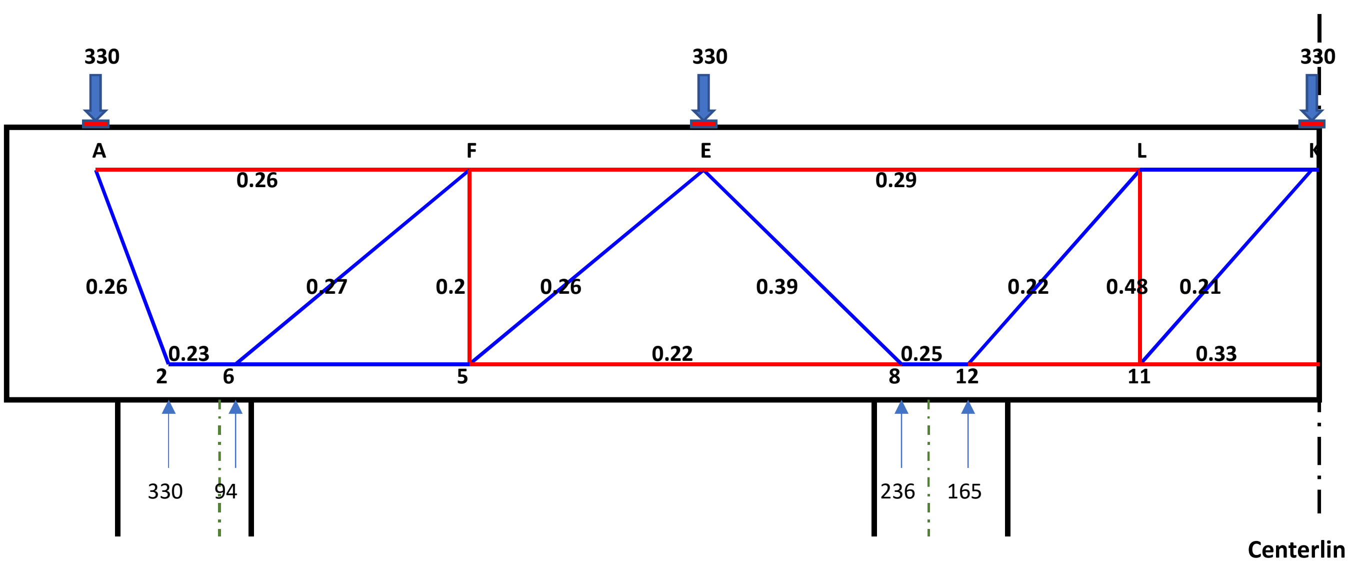


Modification Factor		
1. Are bars epoxy coated?	No	1
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	1

Required development length	19 in
Available development length (L_d)	31 in

Reinforcement Capacity Multiplier:	1.00

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

	Summary				
	Member Code	***Load (k)***	***Capacity (k)***	***Utilization Ratio***	***Result***
	A-F	171	648	0.26	PASS
	E-L	189	648	0.29	PASS
	2-6	-171	-756	0.23	PASS
	5-8	142	648	0.22	PASS
	8-12	-189	-756	0.25	PASS
	11-14	214	648	0.33	PASS
	B-1	-	-	0.00	-
	F-5	94	470	0.20	PASS
	H-7	-	-	0.00	-
	L-11	165	345	0.48	PASS
0	A-2	-372	-1422	0.26	PASS
1	F-6	-183	-686	0.27	PASS
	E-5	-183	-701	0.26	PASS
0	E-8	-406	-1044	0.39	PASS
1	L-12	-260	-1171	0.22	PASS
	K-11	-260	-1246	0.21	PASS
Bearing Areas Nodes at ⇉	A	330	706	0.47	PASS
	E	330	706	0.47	PASS
	K	330	706	0.47	PASS
	2	330	2399	0.14	PASS
	6	94	604	0.16	PASS
	8	236	1601	0.15	PASS
	12	165	1120	0.15	PASS

14. Informational Check: Min Horizontal Crack Control Reinforcement

				Code Required Min skin reinforcement	0.30%
Region	***Area of the Crack Control Rebar (in^2)***	***Spacing of Crack Control Rebar (in)***	***No of layers of Crack Control Rebars***	***Spacing between skin bars***	***Crack Control Reinforcement***
Region 1	0.31	8.0	2	Good	0.22%
Region 2	0.31	8.0	2	Good	0.22%
Region 3	0.31	8.0	2	Good	0.22%
Region 4	0.31	8.0	2	Good	0.22%
Region 5	0.31	8.0	2	Good	0.22%
Region 6	0.31	8.0	2	Good	0.22%

BRIDGE PIER CAP 8

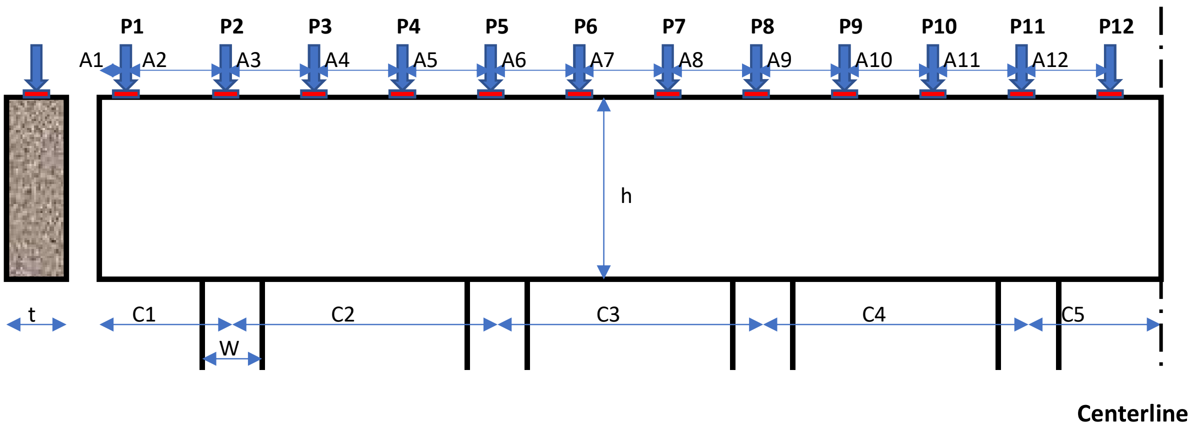
Analysis Input

Bridge Details:

Bridge Name:	Bridge 8	Pier Number:	Southbound (Left)
SFN Number:	570XXXX	Designer:	XXXX
PID No.:	77XXX	Date:	XXXX

1. Total Number of Columns (Piers)	8

☑ Unsymmetrical

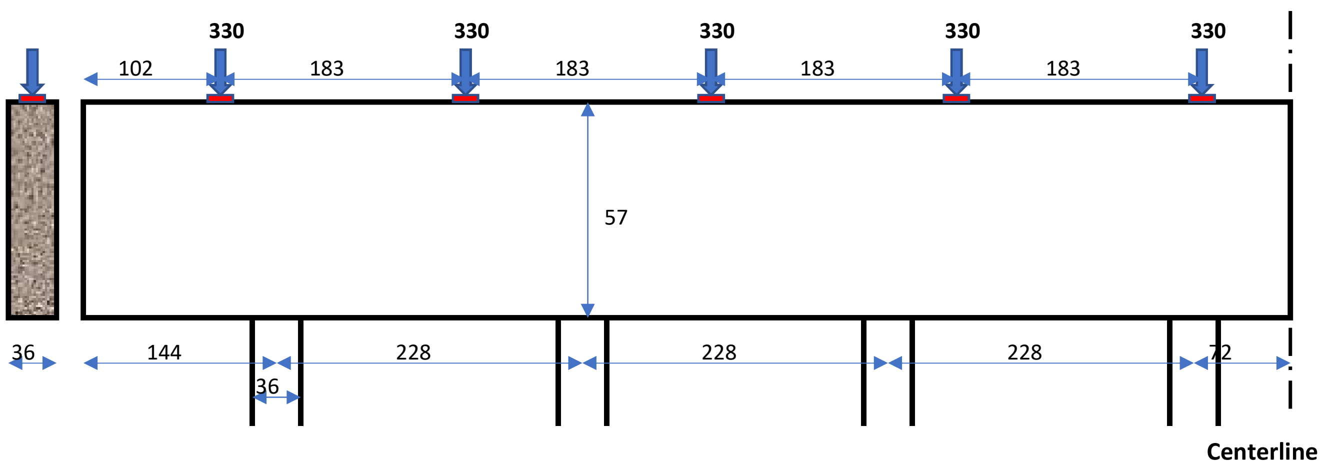


Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	12 ft	0 in	144 in
Distance from center of first column to center of second column (C2)	19 ft	0 in	228 in
Distance from center of second column to center of third column (C3)	19 ft	0 in	228 in
Distance from center of third column to center of fourth column (C4)	19 ft	0 in	228 in
Distance from center of fourth column to centerline of pier cap (C5)	6 ft	0 in	72 in
Column width (W)	36 in	Circular	
Depth of pier cap (h)	57 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	8 ft	6 in	102 in
Spacing between the girders	15 ft	3 in	183 in
Factored Load	330 k		

Factored Load		*Distance*			
P1	330 k	8 ft	6.0 in	102.0 in	A1
P2	0 k	0 ft	0.0 in	0.0 in	A2
P3	330 k	15 ft	3.0 in	183.0 in	A3
P4	0 k	0 ft	0.0 in	0.0 in	A4
P5	0 k	0 ft	0.0 in	0.0 in	A5
P6	330 k	15 ft	3.0 in	183.0 in	A6
P7	0 k	0 ft	0.0 in	0.0 in	A7
P8	0 k	0 ft	0.0 in	0.0 in	A8
P9	330 k	15 ft	3.0 in	183.0 in	A9
P10	0 k	0 ft	0.0 in	0.0 in	A10
P11	330 k	15 ft	3.0 in	183.0 in	A11
P12	0 k	0 ft	0.0 in	0 in	A12

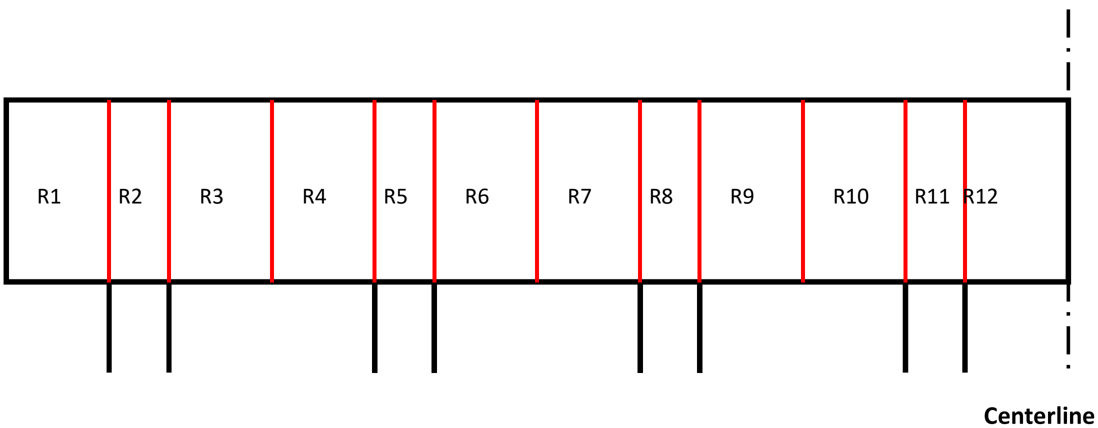


6. Check whether the Pier Cap is Deep			
Region	*Shear span (a)*	*a/d ratio:*	*Result*
R1	37.03 in	0.72	Deep Region
R2	0.00 in	0.00	Zero Region
R3	127.97 in	2.49	Deep Region
R4	78.30 in	1.53	Deep Region
R5	0.00 in	0.00	Zero Region
R6	87 in	1.69	Deep Region
R7	120 in	2.35	Deep Region
R8	0 in	0.00	Zero Region
R9	45 in	0.87	Deep Region
R10	162 in	3.16	Slender Region
R11	3 in	0.05	Deep Region
R12	0 in	0.00	Zero Region

This pier cap is deep.
Please continue with Section 7.

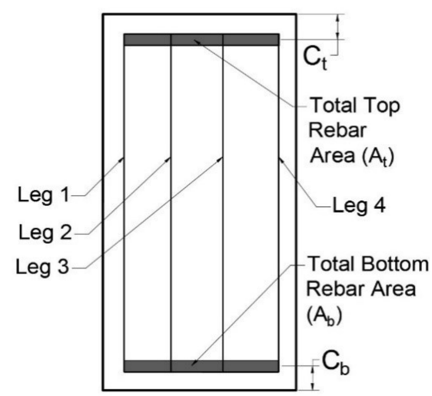
7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC Node multiplier	0.85
CCT Node multiplier	0.75
CTT Node multiplier	0.65



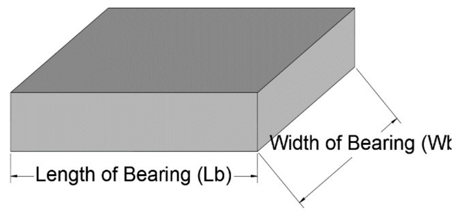
9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in^2, in)***		***Bottom Steel (in^2, in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	12	5	12	5
R2	12	5	12	5
R3	12	5	12	5
R4	12	5	12	5
R5	12	5	12	5
R6	12	5	12	5
R7	12	5	12	5
R8	12	5	12	5
R9	12	5	12	5
R10	12	5	12	5
R11	12	5	12	5
R12	12	5	12	5



9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	4	18 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18 in
R7	4	18 in
R8	4	18 in
R9	4	18 in
R10	4	18 in
R11	4	18 in
R12	4	18 in

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	16.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in



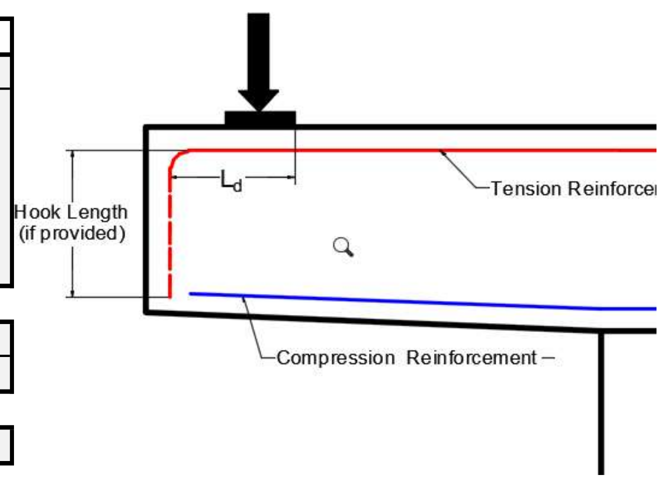
11. Reinforcement Development

Horizontal length available (L_d)	**110 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	**19 in**

It qualifies for 90° hook.

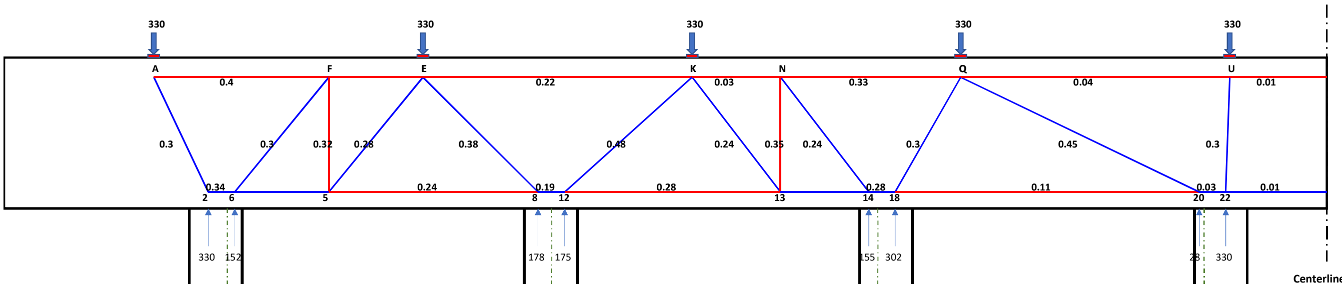
Modification Factor		
1. Are bars epoxy coated?	No	**1**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**



Required development length	**19 in**
Available development length (L_d)	**110 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

	Summary				
	Member Code	***Load (k)***	***Capacity (k)***	***Utilization Ratio***	***Result***
	A-F	260	648	0.40	PASS
	E-K	142	648	0.22	PASS
	K-N	17	648	0.03	PASS
	N-Q	215	648	0.33	PASS
	Q-U	25	648	0.04	PASS
	U-W	6	648	0.01	PASS
	2-6	-260	-756	0.34	PASS
	5-8	154	648	0.24	PASS
	8-12	-142	-756	0.19	PASS
	12-13	181	648	0.28	PASS
	14-18	-215	-756	0.28	PASS
	18-20	72	648	0.11	PASS
	20-22	-25	-756	0.03	PASS
	22-24	-6	-857	0.01	PASS
	B-1	-	-	0.00	-
	F-5	152	476	0.32	PASS
	H-7	-	-	0.00	-
	L-11	-	-	0.00	-
	N-13	155	448	0.35	PASS
	R-17	-	-	0.00	-
	T-19	-	-	0.00	-
	V-21	-	-	0.00	-
0	A-2	-420	-1418	0.30	PASS
1	F-6	-257	-853	0.30	PASS
	E-5	-257	-914	0.28	PASS
0	E-8	-346	-899	0.38	PASS
0	K-12	-368	-769	0.48	PASS
1	K-13	-251	-1027	0.24	PASS
	N-14	-251	-1027	0.24	PASS
0	Q-18	-417	-1398	0.30	PASS
0	Q-20	-101	-227	0.45	PASS
0	U-22	-331	-1084	0.30	PASS
Bearing Areas Nodes at ⇉	A	330	706	0.47	PASS
	E	330	706	0.47	PASS
	K	330	706	0.47	PASS
	Q	330	706	0.47	PASS
	U	330	612	0.54	PASS
	2	330	1659	0.20	PASS
	6	152	674	0.23	PASS
	8	178	1077	0.17	PASS
	12	175	1061	0.17	PASS
	14	155	724	0.21	PASS
	18	302	1414	0.21	PASS
	20	28	168	0.17	PASS
	22	330	2233	0.15	PASS

14. Informational Check: Min Horizontal Crack Control Reinforcement

Code Required Min skin reinforcement					0.30%
Region	***Area of the Crack Control Rebar (in^2)***	***Spacing of Crack Control Rebar (in)***	***No of layers of Crack Control Rebars***	***Spacing between skin bars***	***Crack Control Reinforcement***
Region 1	0.31	8.0	2	Good	0.22%
Region 2	0.31	8.0	2	Good	0.22%
Region 3	0.31	8.0	2	Good	0.22%
Region 4	0.31	8.0	2	Good	0.22%
Region 5	0.31	8.0	2	Good	0.22%
Region 6	0.31	8.0	2	Good	0.22%
Region 7	0.31	6.5	2	Good	0.26%
Region 8	0.31	6.5	2	Good	0.26%
Region 9	0.31	6.5	2	Good	0.26%
Region 10	0.31	6.5	2	Good	0.26%
Region 11	0.31	6.5	2	Good	0.26%
Region 12	0.31	6.5	4	Good	0.53%

10. Appendix B

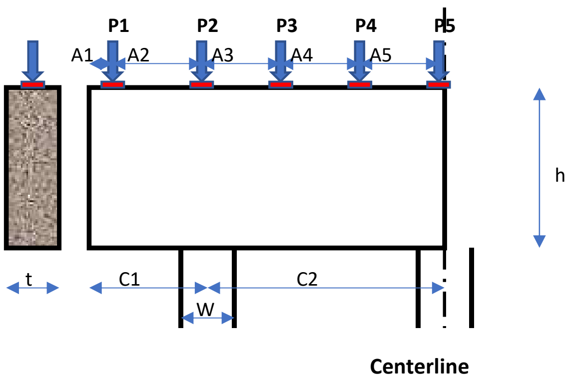
STM-CAP Solved Examples (AASHTO LRFD 2017)

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	3

2. Generate



Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

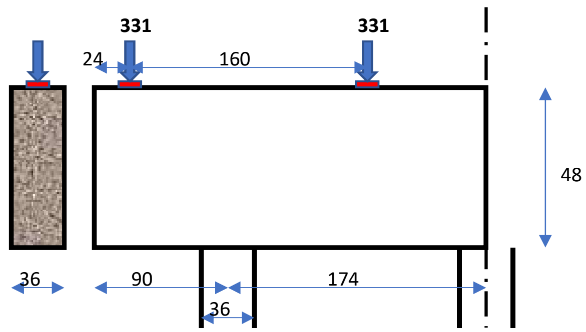
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	7 ft	6.0 in	**90.0 in**
Distance from center of first column to center of second column (C2)	14 ft	6.0 in	**174.0 in**
Column width (W)	36 in	**Circular**	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	0.0 in	**24.0 in**
Spacing Between the Girders	13 ft	4.0 in	**160.0 in**
Factored Load	331 k		

Generate Load Table

Factored Load		***Distance***			
P1	331 k	2 ft	0.0 in	**24.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	331 k	13 ft	4.0 in	**160.0 in**	A3
P4	0 k	0 ft	0.0 in	**0.0 in**	A4
P5	0 k	0 ft	0.0 in	**0.0 in**	A5

5. Generate



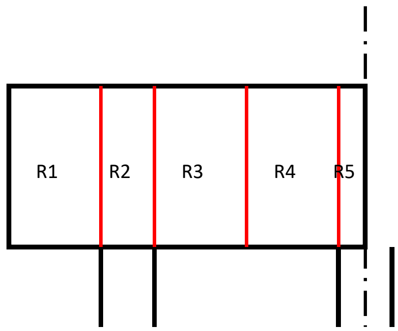
Centerline

6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	**60.3 in**	**1.40**	**Deep Region**
R2	**0.0 in**	**0.00**	**Zero Region**
R3	**81.7 in**	**1.89**	**Deep Region**
R4	**71.0 in**	**1.64**	**Deep Region**
R5	**0.0 in**	**0.00**	**Zero Region**

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.27 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	**0.65**



9. Reinforcement Details

9A. Longitudinal Reinforcement

Region	***Top Steel (in^2, in)***		***Bottom Steel (in^2, in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	13.97	6	7	4.5
R2	13.97	6	7	4.5
R3	13.97	6	7	4.5
R4	13.97	6	7	4.5
R5	13.97	6	7	4.5

9B. Transverse Reinforcement

Region	***No. of Legs***	***Stirrup Spacing***
R1	4	5 in
R2	0	0 in
R3	4	10 in
R4	2	12 in
R5	0	0 in

9C. Min Horizontal Crack Control Reinforcement

Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.44
Spacing (in)	6.0
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.41%**

10. Base Plate Dimensions

Base plate length parallel to the pier cap (L_b)	13.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in

11. Reinforcement Development

Horizontal length available (L_d)	33 in

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.27 in
Enter the length of the hook provided:	30 in
Basic development length	24 in

It qualifies for 90° hook.

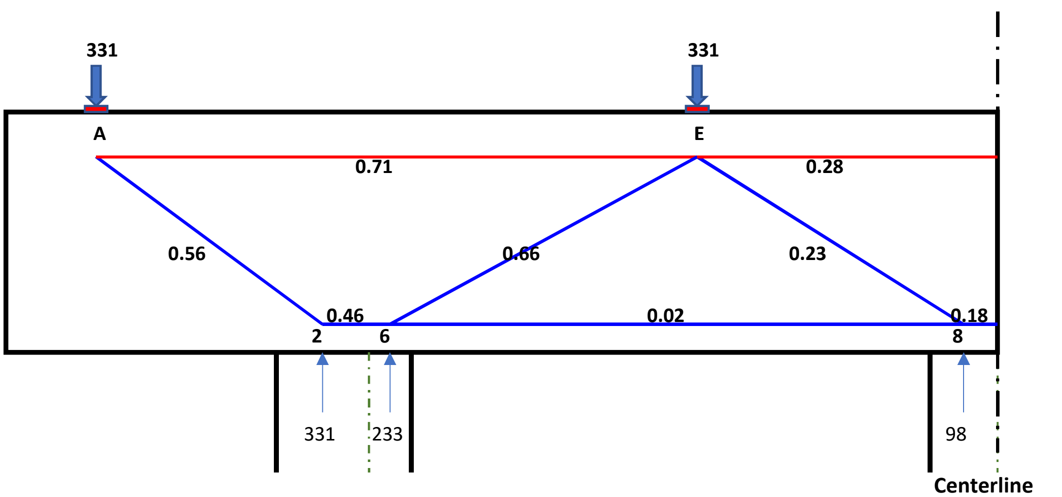
Modification Factor		
1. Are bars epoxy coated?	Yes	1.2
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	1

Required development length	29 in
Available development length (L_d)	33 in

Reinforcement Capacity Multiplier:	1.00

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here

Tie Option	Member Code	Force (k)	Capacity (k)	Utilization Ratio	Result	
	A-E	533	754	0.71	PASS	Top Members
	E-K	210	754	0.28	PASS	
	2-6	-533	-1149	0.46	PASS	Bottom Members
	6-8	-25	-1149	0.02	PASS	
	8-12	-210	-1149	0.18	PASS	
	B-1	0	-	0.00	-	Vertical Members
	F-5	0	-	0.00	-	
	H-7	0	-	0.00	-	
0	A-2	-627	-1117	0.56	PASS	Inclined Members
0	E-6	-559	-846	0.66	PASS	
0	E-8	-210	-910	0.23	PASS	
Bearing Areas — Nodes at ⇉	A	331	1028	0.32	PASS	1
	E	331	955	0.35	PASS	
	2	331	1422	0.23	PASS	2
	6	233	1001	0.23	PASS	
	8	98	1212	0.08	PASS	

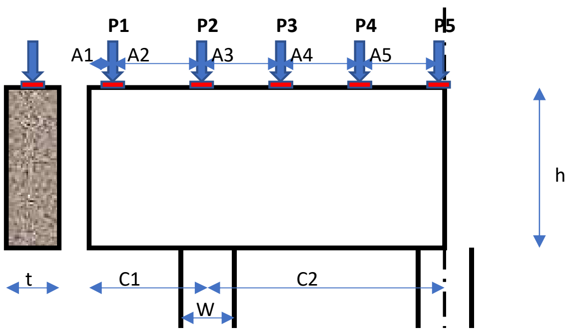
Re-Generate Output Model

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	3

2. Generate



Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

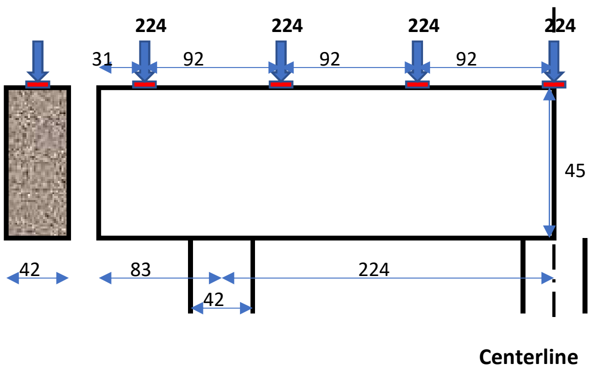
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	6 ft	11.0 in	**83.0 in**
Distance from center of first column to center of second column (C2)	18 ft	8.0 in	**224.0 in**
Column width (W)	42 in	**Circular**	
Depth of pier cap (h)	45 in		
Thickness of pier cap (t)	42 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	7.0 in	**31.0 in**
Spacing Between the Girders	7 ft	8.0 in	**92.0 in**
Factored Load	224 k		

Generate Load Table

Factored Load		***Distance***			
P1	224 k	2 ft	7.0 in	**31.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	224 k	7 ft	8.0 in	**92.0 in**	A3
P4	224 k	7 ft	8.0 in	**92.0 in**	A4
P5	224 k	7 ft	8.0 in	**92.0 in**	A5

5. Generate

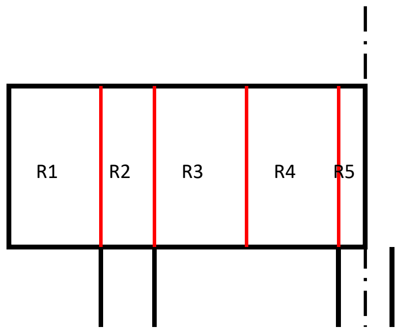


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	**40.4 in**	**1.00**	**Deep Region**
R2	**0.0 in**	**0.00**	**Zero Region**
R3	**30.6 in**	**0.76**	**Deep Region**
R4	**77.4 in**	**1.91**	**Deep Region**
R5	**4.1 in**	**0.10**	**Deep Region**

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	**0.65**



9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in^2, in)***		***Bottom Steel (in^2, in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	9.46	4.45	8	3.15
R2	9.46	4.45	8	3.15
R3	9.46	4.45	8	3.15
R4	9.46	4.45	8	3.15
R5	9.46	4.45	8	3.15

9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	4	10 in
R2	4	10 in
R3	4	10 in
R4	4	10 in
R5	4	10 in

9C. Min Horizontal Crack Control Reinforcement	
Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.31
Spacing (in)	6.0
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.25%**

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	20.0 in
Base plate width perpendicular to the pier cap (W_b)	13.0 in

11. Reinforcement Development

Horizontal length available (L_d)	41 in

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	19 in

It qualifies for 90° hook.

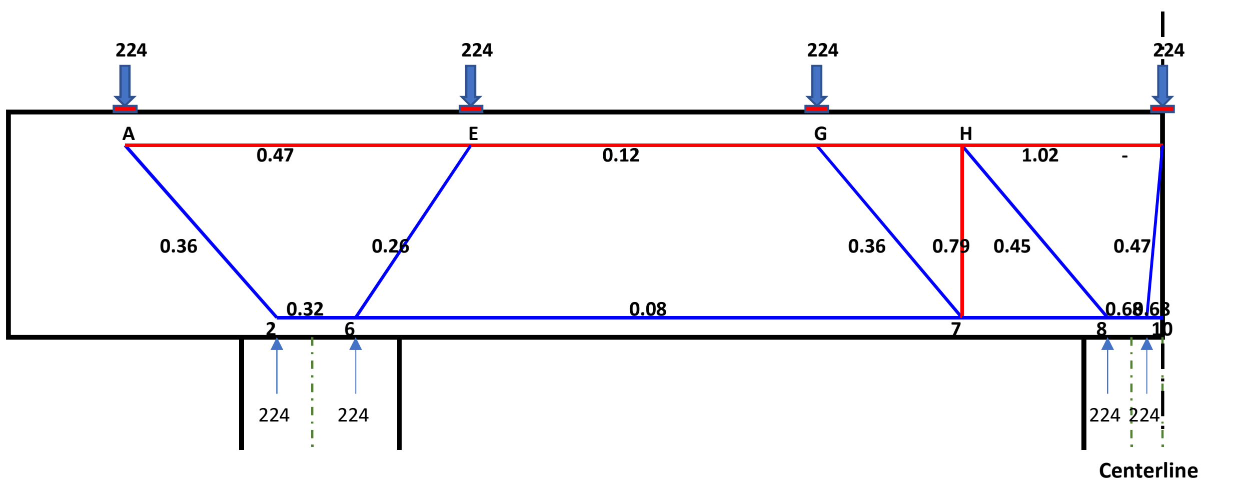
Modification Factor		
1. Are bars epoxy coated?	Yes	1.2
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	1

Required development length	23 in
Available development length (L_d)	41 in

Reinforcement Capacity Multiplier:	1.00

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Tie Option	Member Code	Force (k)	Capacity (k)	Utilization Ratio	Result	
	A-E	242	511	0.47	PASS	Top Members
	E-G	59	511	0.12	PASS	
	H-I	520	511	1.02	Flexure Overloaded	
	2-6	-242	-765	0.32	PASS	Bottom Members
	6-7	-59	-765	0.08	PASS	
	8-10	-520	-765	0.68	PASS	
	10-12	-520	-765	0.68	PASS	
	B-1	0	-	0.00	-	Vertical Members
	F-5	0	-	0.00	-	
	H-7	224	284	0.79	PASS	
	J-9	0	-	0.00	-	
0	A-2	-330	-921	0.36	PASS	Inclined Members
0	E-6	-289	-1117	0.26	PASS	
1	G-7	-324	-904	0.36	PASS	
	H-8	-319	-708	0.45	PASS	
0	I-10	-224	-472	0.47	PASS	
Bearing Areas — Nodes at ⇉	A	224	655	0.34	PASS	1
	E	224	655	0.34	PASS	
	G	224	655	0.34	PASS	
	I	224	655	0.34	PASS	
	2	224	873	0.26	PASS	2
	6	224	873	0.26	PASS	
	8	224	436	0.51	PASS	
	10	224	436	0.51	PASS	

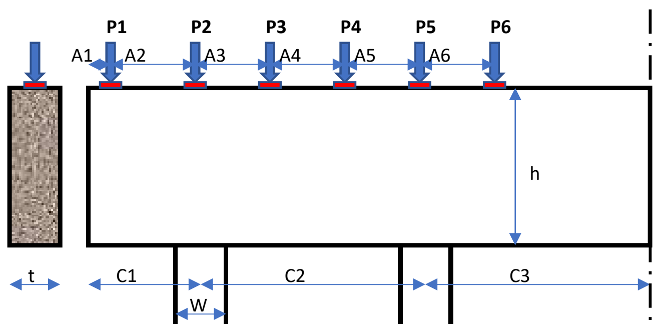
Re-Generate Output Model

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	4

2. Generate



Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

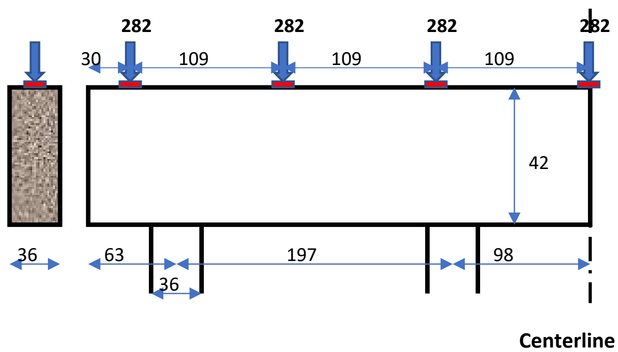
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	5 ft	3 in	**63.0 in**
Distance from center of first column to center of second column (C2)	16 ft	5 in	**197.0 in**
Distance from center of second column to centerline of pier cap (C3)	8 ft	2 in	**98.0 in**
Column width (W)	36 in	Circular	
Depth of pier cap (h)	42 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	6.0 in	**30.0 in**
Spacing Between the Girders	9 ft	1.0 in	**109.0 in**
Factored Load	282 k		

Generate Load Table

Factored Load		***Distance***			
P1	282 k	2 ft	6.0 in	**30.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	282 k	9 ft	1.0 in	**109.0 in**	A3
P4	0 k	0 ft	0.0 in	**0.0 in**	A4
P5	282 k	9 ft	1.0 in	**109.0 in**	A5
P6	282 k	9 ft	1.0 in	**109.0 in**	A6

5. Generate

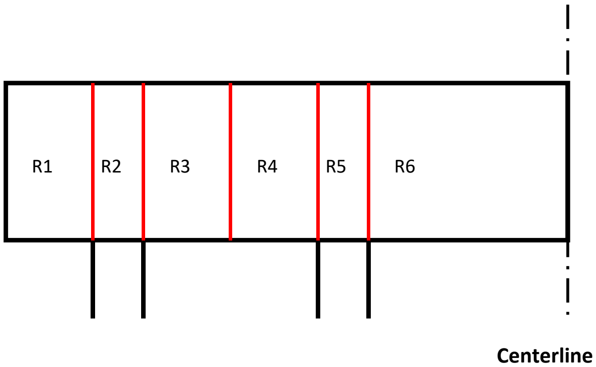


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	26.2 in	0.69	Deep Region
R2	0.0 in	0.00	Zero Region
R3	64.8 in	1.72	Deep Region
R4	105.9 in	2.80	Slender Region
R5	7.4 in	0.19	Deep Region
R6	87 in	2.29	Slender Region

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	0.65



9. Reinforcement Details

9A. Longitudinal Reinforcement

Region	Top Steel (in^2, in)		Bottom Steel (in^2, in)	
	Total Area (A_t)	Centroid (C_t)	Total Area (A_b)	Centroid (C_b)
R1	8	4.1	8	4.1
R2	8	4.1	8	4.1
R3	8	4.1	8	4.1
R4	8	4.1	8	4.1
R5	8	4.1	8	4.1
R6	8	4.1	8	4.1

9B. Transverse Reinforcement

Region	No. of Legs	Stirrup Spacing
R1	4	7 in
R2	0	0 in
R3	4	12 in
R4	4	12 in
R5	0	0 in
R6	4	16 in

9C. Min Horizontal Crack Control Reinforcement

Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.31
Spacing (in)	8.0
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.22%**

10. Base Plate Dimensions

Base plate length parallel to the pier cap (L_b)	21.0 in
Base plate width perpendicular to the pier cap (W_b)	13.0 in

11. Reinforcement Development

Horizontal length available (L_d)	40 in

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	19 in

It qualifies for 90° hook.

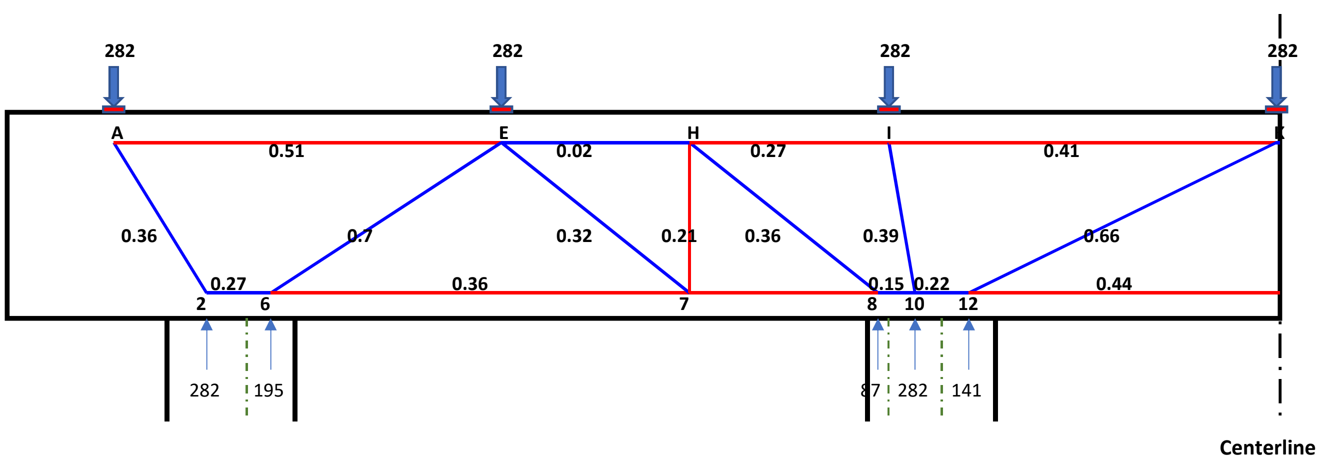
Modification Factor		
1. Are bars epoxy coated?	Yes	1.2
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	1

Required development length	23 in
Available development length (L_d)	40 in

Reinforcement Capacity Multiplier:	1.00

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Tie Option	Member Code	Force (k)	Capacity (k)	Utilization Ratio	Result	Group
	A-E	218	432	0.51	PASS	Top Members
	E-H	-19	-804	0.02	PASS	Top Members
	I-K	177	432	0.41	PASS	Top Members
	K-Q	0	432	0.00	-	Top Members
	2-6	-218	-804	0.27	PASS	Bottom Members
	6-7	155	432	0.36	PASS	Bottom Members
	8-10	-118	-804	0.15	PASS	Bottom Members
	10-12	-177	-804	0.22	PASS	Bottom Members
	12-14	189	432	0.44	PASS	Bottom Members
	B-1	0	-	0.00	-	Vertical Members
	F-5	0	-	0.00	-	Vertical Members
	H-7	87	415	0.21	PASS	Vertical Members
	J-9	0	-	0.00	-	Vertical Members
	L-11	0	-	0.00	-	Vertical Members
0	A-2	-357	-981	0.36	PASS	Inclined Members
0	E-6	-421	-600	0.70	PASS	Inclined Members
1	E-7	-162	-511	0.32	PASS	Inclined Members
	H-8	-162	-456	0.36	PASS	Inclined Members
0	I-10	-288	-748	0.39	PASS	Inclined Members
0	K-12	-391	-595	0.66	PASS	Inclined Members
Bearing Areas Nodes at ⇉	A	282	688	0.41	PASS	1
	E	282	688	0.41	PASS	1
	I	282	688	0.41	PASS	1
	K	282	688	0.41	PASS	1
	2	282	759	0.37	PASS	2
	6	195	524	0.37	PASS	2
	8	87	219	0.40	PASS	2
	10	282	709	0.40	PASS	2
	12	141	354	0.40	PASS	2

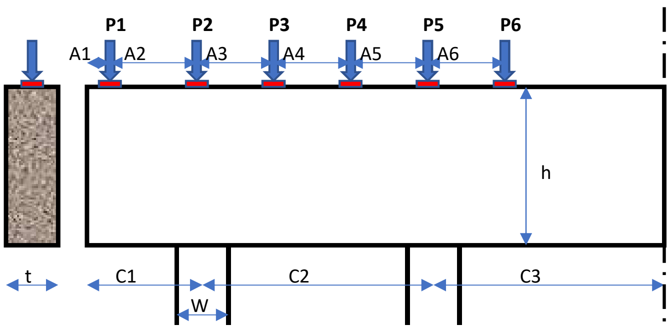
Re-Generate Output Model

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	4

2. Generate



Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

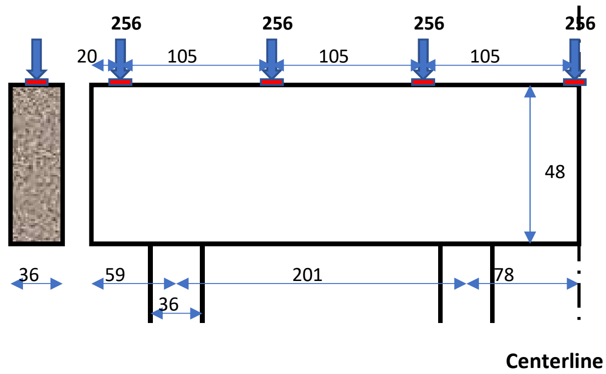
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	4 ft	11 in	**59.0 in**
Distance from center of first column to center of second column (C2)	16 ft	9 in	**201.0 in**
Distance from center of second column to centerline of pier cap (C3)	6 ft	6 in	**78.0 in**
Column width (W)	36 in	**Circular**	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	1 ft	8.0 in	**20.0 in**
Spacing Between the Girders	8 ft	9.0 in	**105.0 in**
Factored Load	256 k		

Generate Load Table

Factored Load		***Distance***			
P1	256 k	1 ft	8.0 in	**20.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	256 k	8 ft	9.0 in	**105.0 in**	A3
P4	256 k	8 ft	9.0 in	**105.0 in**	A4
P5	0 k	0 ft	0.0 in	**0.0 in**	A5
P6	256 k	8 ft	9.0 in	**105.0 in**	A6

5. Generate

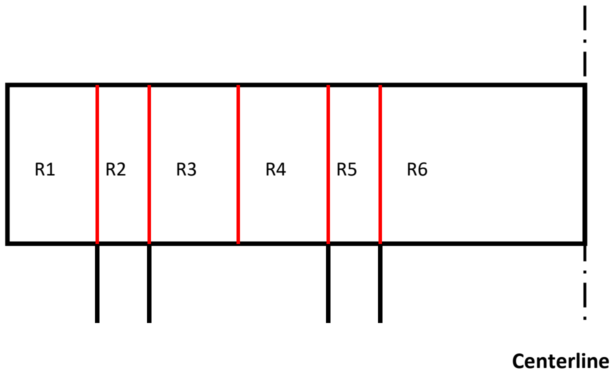


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	30.9 in	0.71	Deep Region
R2	0.0 in	0.00	Zero Region
R3	56.1 in	1.30	Deep Region
R4	21.7 in	0.50	Deep Region
R5	0.0 in	0.00	Zero Region
R6	65 in	1.51	Deep Region

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	**0.65**



9. Reinforcement Details

9A. Longitudinal Reinforcement

Region	Top Steel (in^2, in)		Bottom Steel (in^2, in)	
	Total Area (A_t)	Centroid (C_t)	Total Area (A_b)	Centroid (C_b)
R1	8	4.5	9	4.2
R2	8	4.5	9	4.2
R3	8	4.5	9	4.2
R4	8	4.5	9	4.2
R5	8	4.5	9	4.2
R6	8	4.5	9	4.2

9B. Transverse Reinforcement

Region	No. of Legs	Stirrup Spacing
R1	4	7 in
R2	0	0 in
R3	4	12 in
R4	4	12 in
R5	0	0 in
R6	4	16 in

9C. Min Horizontal Crack Control Reinforcement

Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.31
Spacing (in)	5.5
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.31%**

10. Base Plate Dimensions

Base plate length parallel to the pier cap (L_b)	11.5 in
Base plate width perpendicular to the pier cap (W_b)	19.0 in

11. Reinforcement Development

Horizontal length available (L_d)	**26 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	**19 in**

It qualifies for 90° hook.

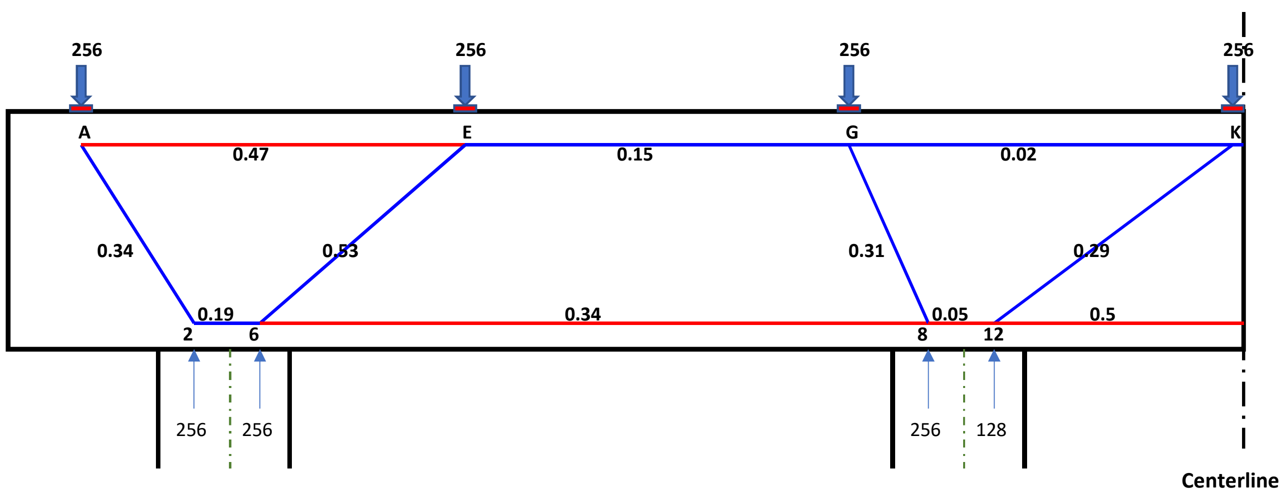
Modification Factor		
1. Are bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**

Required development length	**23 in**
Available development length (L_d)	**26 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input	Member Code	Force (k)	Capacity (k)	Utilization Ratio	Result	Group
	A-E	201	432	0.47	PASS	Top Members
	E-G	-164	-1067	0.15	PASS	
	G-K	-23	-1203	0.02	PASS	
	K-Q	-23	-1203	0.02	PASS	
	2-6	-201	-1079	0.19	PASS	Bottom Members
	6-8	164	486	0.34	PASS	
	8-12	23	486	0.05	PASS	
	12-14	245	486	0.50	PASS	
Input 0 for "Do not use Tie"	B-1	0	-	0.00	-	Vertical Members
Input 1 for "Use Tie"	F-5	0	-	0.00	-	
Input Your Option Down Here	H-7	0	-	0.00	-	
↓↓↓↓↓↓↓	L-11	0	-	0.00	-	
0	A-2	-326	-957	0.34	PASS	Inclined Members
0	E-6	-446	-838	0.53	PASS	
0	G-8	-293	-945	0.31	PASS	
0	K-12	-257	-894	0.29	PASS	
Bearing Areas Nodes at ⇉	A	256	857	0.30	PASS	1
	E	256	857	0.30	PASS	
	G	256	1040	0.25	PASS	
	K	256	1040	0.25	PASS	
	2	256	1212	0.21	PASS	2
	6	256	998	0.26	PASS	
	8	256	1235	0.21	PASS	
	12	128	618	0.21	PASS	

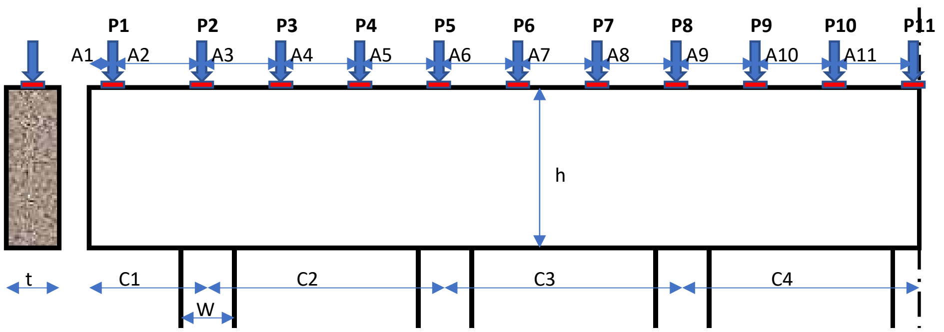
Re-Generate Output Model

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	7

2. Generate



Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

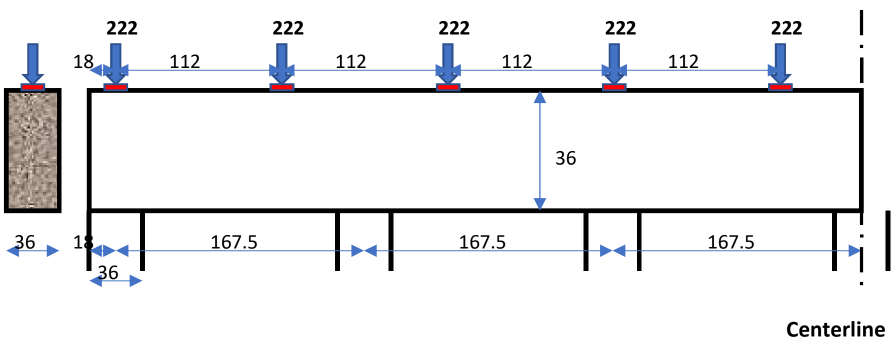
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	1 ft	6 in	**18.0 in**
Distance from center of first column to center of second column (C2)	13 ft	12 in	**167.5 in**
Distance from center of second column to center of third column (C3)	13 ft	12 in	**167.5 in**
Distance from center of third column to center of fourth column (C4)	13 ft	12 in	**167.5 in**
Column width (W)	36 in	**Circular**	
Depth of pier cap (h)	36 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	1 ft	6.0 in	**18.0 in**
Spacing Between the Girders	9 ft	4.0 in	**112.0 in**
Factored Load	222 k		

Generate Load Table

Factored Load		*Distance*			
P1	0 k	0 ft	0.0 in	0.0 in	A1
P2	222 k	1 ft	6.0 in	18.0 in	A2
P3	222 k	9 ft	4.0 in	112.0 in	A3
P4	0 k	0 ft	0.0 in	0.0 in	A4
P5	0 k	0 ft	0.0 in	0.0 in	A5
P6	222 k	9 ft	4.0 in	112.0 in	A6
P7	0 k	0 ft	0.0 in	0.0 in	A7
P8	222 k	9 ft	4.0 in	112.0 in	A8
P9	222 k	9 ft	4.0 in	112.0 in	A9
P10	0 k	0 ft	0.0 in	0.0 in	A10
P11	0 k	0 ft	0.0 in	0.0 in	A11

5. Generate

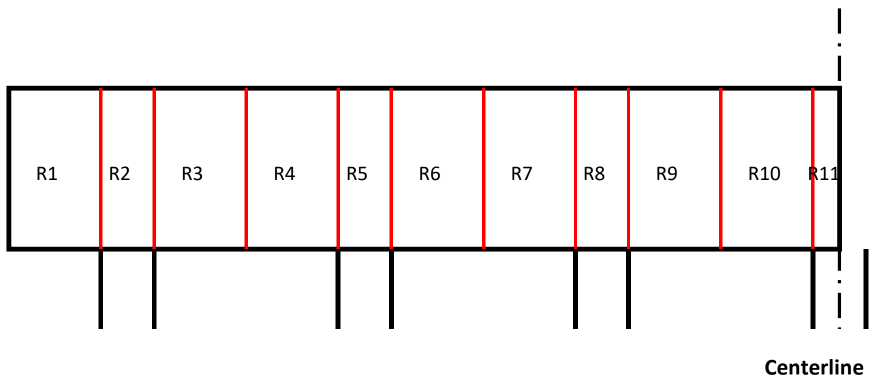


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	0.0 in	0.00	Zero Region
R2	4.5 in	0.14	Deep Region
R3	98.5 in	3.04	Slender Region
R4	46.5 in	1.44	Deep Region
R5	0.0 in	0.00	Zero Region
R6	47 in	1.46	Deep Region
R7	97 in	2.98	Slender Region
R8	1 in	0.03	Deep Region
R9	99 in	3.04	Slender Region
R10	46 in	1.40	Deep Region
R11	0 in	0.00	Zero Region

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	**0.65**



9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in^2, in)***		***Bottom Steel (in^2, in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	7.9	4.2	7.9	4.2
R2	7.9	4.2	7.9	4.2
R3	7.9	4.2	7.9	4.2
R4	7.9	4.2	7.9	4.2
R5	7.9	4.2	7.9	4.2
R6	7.9	4.2	7.9	4.2
R7	7.9	4.2	7.9	4.2
R8	7.9	4.2	7.9	4.2
R9	7.9	4.2	7.9	4.2
R10	7.9	4.2	7.9	4.2
R11	7.9	4.2	7.9	4.2

9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	0	0 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18 in
R7	4	20 in
R8	4	20 in
R9	4	20 in
R10	4	18 in
R11	4	18 in

9C. Min Horizontal Crack Control Reinforcement	
Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.31
Spacing (in)	7.0
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.25%**

10. Base Plate Dimensions	
Base plate length parallel to the pier cap (L_b)	19.0 in
Base plate width perpendicular to the pier cap (W_b)	12.0 in

11. Reinforcement Development

Horizontal length available	**25 in**

Bottom Tension Bars		
Enter the Diameter of the Bottom longitudinal bar:	1.00 in	
Enter the Length of the hook Provided:	27 in	
Basic Development Length	**19 in**	*It qualifies for 90° hook.*

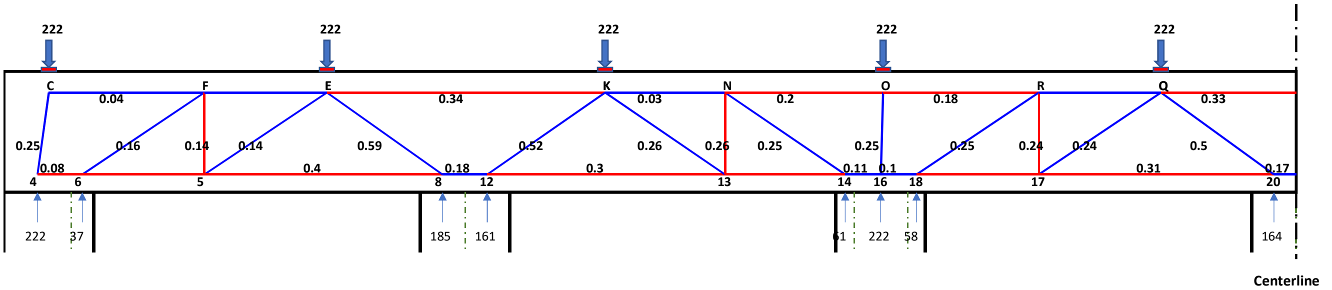
Modification Factor		
1. Are those bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 Bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**

Required development length	**23 in**
Available development length (L_d)	**25 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Input	Member Code	Force (k)	Capacity (k)	Utilization Ratio	Result	
	Summary					
	C-F	-36	-808	0.04	PASS	Top Members
	E-K	144	427	0.34	PASS	
	K-N	-23	-808	0.03	PASS	
	O-R	78	427	0.18	PASS	
	Q-W	139	427	0.33	PASS	
	4-6	36	427	0.08	PASS	Bottom Members
	5-8	170	427	0.40	PASS	
	8-12	-144	-808	0.18	PASS	
	12-13	129	427	0.30	PASS	
	14-16	-86	-808	0.11	PASS	
	16-18	-78	-808	0.10	PASS	
	17-20	131	427	0.31	PASS	
	20-24	-139	-808	0.17	PASS	
	D-3	0	-	0.00	-	Vertical Members
	F-5	37	271	0.14	PASS	
	H-7	0	-	0.00	-	
	L-11	0	-	0.00	-	
	N-13	61	237	0.26	PASS	
	P-15	0	-	0.00	-	
	R-17	58	244	0.24	PASS	
	T-19	0	-	0.00	-	
0	C-4	-225	-912	0.25	PASS	Inclined Members
1	F-6	-77	-472	0.16	PASS	
	E-5	-76	-531	0.14	PASS	
0	E-8	-364	-622	0.59	PASS	
0	K-12	-318	-616	0.52	PASS	
1	K-13	-123	-475	0.26	PASS	
	N-14	-123	-495	0.25	PASS	
0	O-16	-222	-873	0.25	PASS	
1	R-18	-119	-469	0.25	PASS	
	Q-17	-119	-489	0.24	PASS	
0	Q-20	-316	-627	0.50	PASS	
	C	222	575	0.39	PASS	1
	E	222	575	0.39	PASS	
	K	222	575	0.39	PASS	
	O	222	575	0.39	PASS	
	Q	222	575	0.39	PASS	
	4	222	1097	0.20	PASS	2
	6	37	185	0.20	PASS	
	8	185	685	0.27	PASS	
	12	161	597	0.27	PASS	
	14	61	230	0.27	PASS	
	16	222	834	0.27	PASS	
	18	58	218	0.27	PASS	
	20	164	641	0.26	PASS	

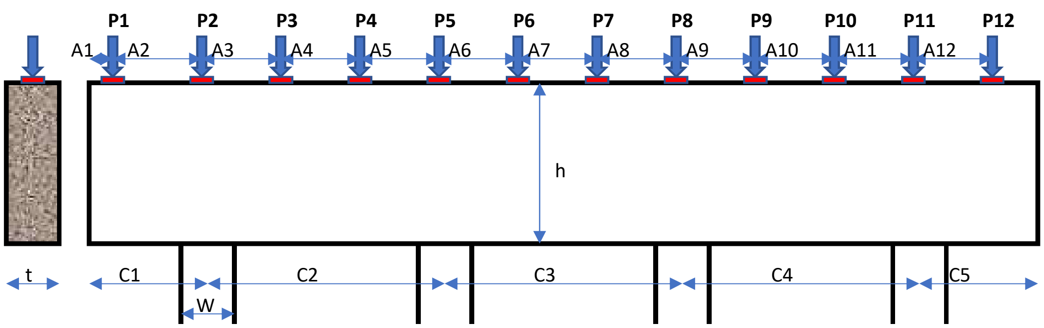
Re-Generate Output Model

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	4	Asymmetrical

2. Generate



Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

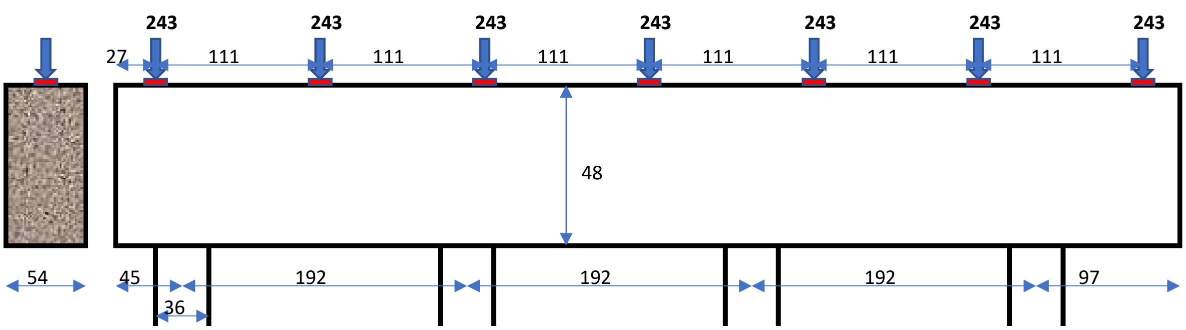
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	3 ft	9.0 in	45.0 in
Distance from center of first column to center of second column (C2)	16 ft	0.0 in	192.0 in
Distance from center of second column to center of third column (C3)	16 ft	0.0 in	192.0 in
Distance from center of third column to center of fourth pier cap (C4)	16 ft	0.0 in	192.0 in
Distance from center of fourth column to the end of the pier cap (C4)	8 ft	1.0 in	97.0 in
Column width (W)	36 in	Circular	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	54 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	3.0 in	27.0 in
Spacing Between the Girders	9 ft	3.0 in	111.0 in
Factored Load	243 k		

Generate Load Table

Factored Load		*Distance*			
P1	243 k	2 ft	3.0 in	27.0 in	A1
P2	0 k	0 ft	0.0 in	0.0 in	A2
P3	243 k	9 ft	3.0 in	111.0 in	A3
P4	0 k	0 ft	0.0 in	0.0 in	A4
P5	243 k	9 ft	3.0 in	111.0 in	A5
P6	243 k	9 ft	3.0 in	111.0 in	A6
P7	0 k	0 ft	0.0 in	0.0 in	A7
P8	0 k	0 ft	0.0 in	0.0 in	A8
P9	243 k	9 ft	3.0 in	111.0 in	A9
P10	243 k	9 ft	3.0 in	111.0 in	A10
P11	0 k	0 ft	0.0 in	0.0 in	A11
P12	243 k	9 ft	3.0 in	111.0 in	A12

5. Generate

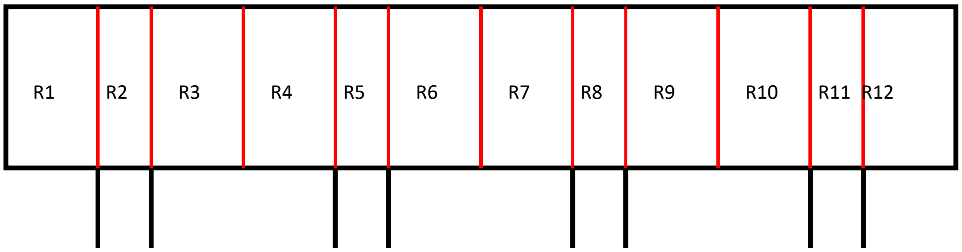


6. Check whether the Pier Cap is Deep			
Region	*Shear span (a)*	*a/d ratio:*	*Result*
R1	11.9 in	0.27	Deep Region
R2	0.0 in	0.00	Zero Region
R3	81.1 in	1.88	Deep Region
R4	85.7 in	1.98	Deep Region
R5	10.8 in	0.25	Deep Region
R6	109 in	2.51	Slender Region
R7	58 in	1.34	Deep Region
R8	0 in	0.00	Zero Region
R9	17 in	0.39	Deep Region
R10	30 in	0.70	Deep Region
R11	0 in	0.00	Zero Region
R12	45 in	1.04	Deep Region

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.27 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	**0.65**



9. Reinforcement Details

9A. Longitudinal Reinforcement				
Region	***Top Steel (in^2, in)***		***Bottom Steel (in^2, in)***	
	Total Area (A_t)	***Centroid (C_t)***	***Total Area (A_b)***	***Centroid (C_b)***
R1	22.86	5.5	11.43	3
R2	22.86	5.5	11.43	3
R3	22.86	5.5	11.43	3
R4	22.86	5.5	11.43	3
R5	22.86	5.5	11.43	3
R6	22.86	5.5	11.43	3
R7	22.86	5.5	11.43	3
R8	22.86	5.5	11.43	3
R9	22.86	5.5	11.43	3
R10	22.86	5.5	11.43	3
R11	22.86	5.5	11.43	3
R12	22.86	5.5	11.43	3

9B. Transverse Reinforcement		
Region	***No. of Legs***	***Stirrup Spacing***
R1	0	0 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18 in
R7	4	20 in
R8	4	20 in
R9	4	20 in
R10	4	18 in
R11	4	18 in
R12	0	0 in

9C. Min Horizontal Crack Control Reinforcement	
Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.20
Spacing (in)	5.0
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.15%**

10. Base Plate Dimensions

Base plate length parallel to the pier cap (L_b)	13.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in

11. Reinforcement Development

Horizontal length available (L_d)	**32 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.27 in
Enter the length of the hook provided:	30 in
Basic development length	**24 in**

It qualifies for 90° hook.

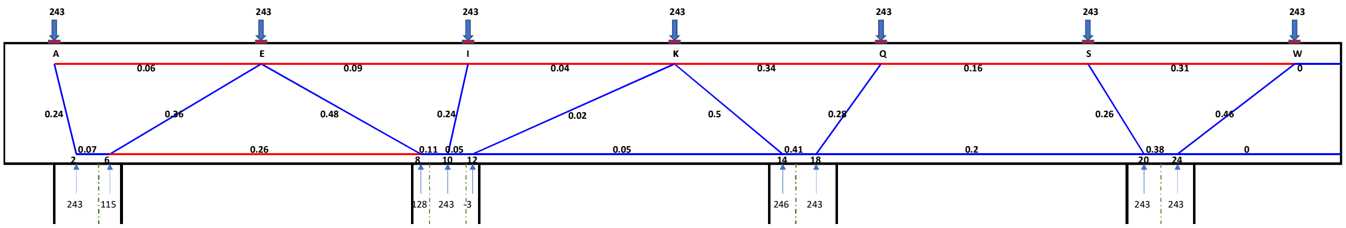
Modification Factor		
1. Are bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**

Required development length	**29 in**
Available development length (L_d)	**32 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Tie Input	Member Code	Force (k)	Capacity (k)	Utilization Ratio	Result	
	Summary					
	A-E	73	1234	0.06	PASS	Top Members
	E-I	114	1234	0.09	PASS	
	I-K	48	1234	0.04	PASS	
	K-Q	417	1234	0.34	PASS	
	Q-S	202	1234	0.16	PASS	
	S-W	387	1234	0.31	PASS	
	W+	0	1234	0.00	-	
	2-6	-73	-1025	0.07	PASS	Bottom Members
	6-8	164	617	0.26	PASS	
	8-10	-114	-1025	0.11	PASS	
	10-12	-48	-1025	0.05	PASS	
	12-14	-55	-1025	0.05	PASS	
	14-18	-417	-1025	0.41	PASS	
	18-20	-202	-1025	0.20	PASS	
	20-24	-387	-1025	0.38	PASS	
	24+	0	617	0.00	-	
	B-1	0	-	0.00	-	Vertical Members
	F-5	0	-	0.00	-	
	H-7	0	-	0.00	-	
	J-9	0	-	0.00	-	
	L-11	0	-	0.00	-	
	N-13	0	-	0.00	-	
	R-17	0	-	0.00	-	
	T-19	0	-	0.00	-	
	X-23	0	-	0.00	-	
0	A-2	-254	-1063	0.24	PASS	Inclined Members
0	E-6	-263	-732	0.36	PASS	
0	E-8	-305	-640	0.48	PASS	
0	I-10	-252	-1050	0.24	PASS	
0	K-12	-8	-547	0.01	PASS	
0	K-14	-437	-881	0.50	PASS	
0	Q-18	-324	-1148	0.28	PASS	
0	S-20	-305	-1157	0.26	PASS	
0	W-24	-457	-992	0.46	PASS	
Bearing Areas — Nodes at ⇉	A	243	688	0.35	PASS	1
	E	243	688	0.35	PASS	
	I	243	688	0.35	PASS	
	K	243	688	0.35	PASS	
	Q	243	688	0.35	PASS	
	S	243	688	0.35	PASS	
	W	243	688	0.35	PASS	
	2	243	870	0.28	PASS	2
	6	115	413	0.28	PASS	
	8	128	446	0.29	PASS	
	10	243	847	0.29	PASS	
	12	-3	-10	0.29	PASS	
	14	246	645	0.38	PASS	
	18	243	638	0.38	PASS	
	20	243	641	0.38	PASS	
	24	243	641	0.38	PASS	

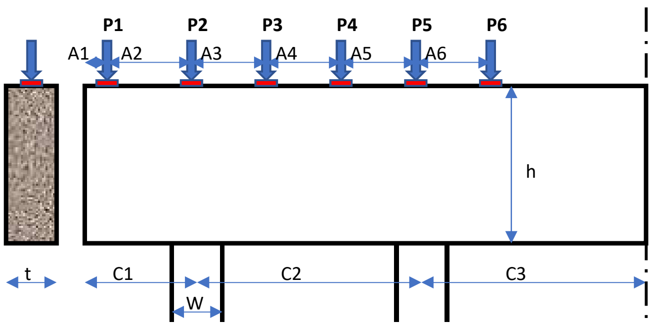
Re-Generate Output Model

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	4

2. Generate



Centerline

Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

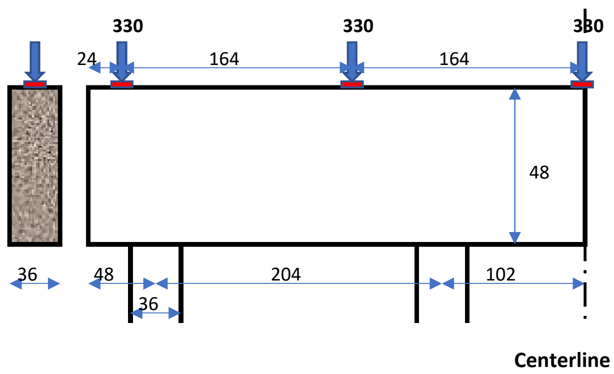
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	4 ft	0 in	**48.0 in**
Distance from center of first column to center of second column (C2)	17 ft	0 in	**204.0 in**
Distance from center of second column to centerline of pier cap (C3)	8 ft	6 in	**102.0 in**
Column width (W)	36 in	Circular	
Depth of pier cap (h)	48 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	2 ft	0.0 in	**24.0 in**
Spacing Between the Girders	13 ft	8.0 in	**164.0 in**
Factored Load	330 k		

Generate Load Table

Factored Load		***Distance***			
P1	330 k	2 ft	0.0 in	**24.0 in**	A1
P2	0 k	0 ft	0.0 in	**0.0 in**	A2
P3	330 k	13 ft	8.0 in	**164.0 in**	A3
P4	0 k	0 ft	0.0 in	**0.0 in**	A4
P5	0 k	0 ft	0.0 in	**0.0 in**	A5
P6	330 k	13 ft	8.0 in	**164.0 in**	A6

5. Generate

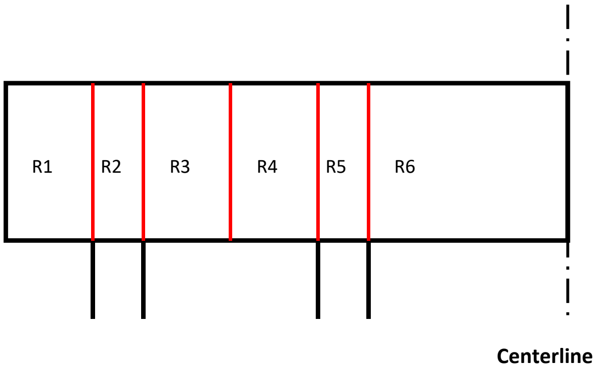


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	**19.7 in**	**0.46**	**Deep Region**
R2	**0.0 in**	**0.00**	**Zero Region**
R3	**126.3 in**	**2.92**	**Slender Region**
R4	**53.3 in**	**1.23**	**Deep Region**
R5	**0.0 in**	**0.00**	**Zero Region**
R6	**93 in**	**2.15**	**Slender Region**

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	**0.65**



9. Reinforcement Details

9A. Longitudinal Reinforcement

Region	Top Steel (in^2, in)		Bottom Steel (in^2, in)	
	Total Area (A_t)	Centroid (C_t)	Total Area (A_b)	Centroid (C_b)
R1	12	5	12	5
R2	12	5	12	5
R3	12	5	12	5
R4	12	5	12	5
R5	12	5	12	5
R6	12	5	12	5

9B. Transverse Reinforcement

Region	No. of Legs	Stirrup Spacing
R1	4	18 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18.0 in

9C. Min Horizontal Crack Control Reinforcement

Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.31
Spacing (in)	9.0
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.19%**

10. Base Plate Dimensions

Base plate length parallel to the pier cap (L_b)	16.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in

11. Reinforcement Development

Horizontal length available (L_d)	31 in

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	19 in

It qualifies for 90° hook.

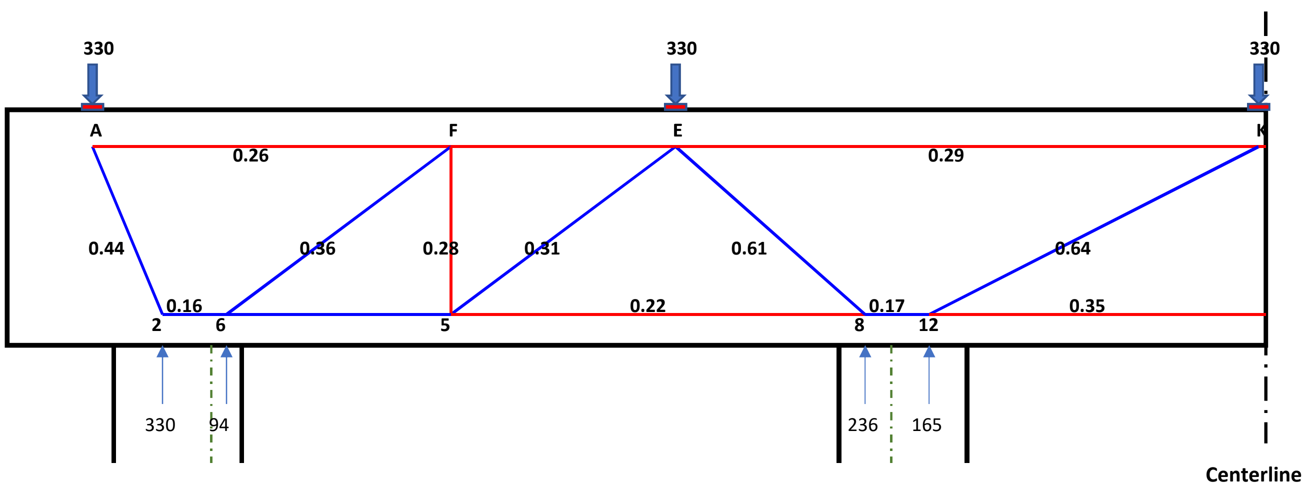
Modification Factor		
1. Are bars epoxy coated?	Yes	1.2
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	1

Required development length	23 in
Available development length (L_d)	31 in

Reinforcement Capacity Multiplier:	1.00

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
↓↓↓↓↓↓↓

Input	Summary					Group
	Member Code	Force (k)	Capacity (k)	Utilization Ratio	Result	
	A-F	171	648	0.26	PASS	Top Members
	E-K	187	648	0.29	PASS	
	K-Q	187	648	0.29	PASS	
	2-6	-171	-1102	0.16	PASS	Bottom Members
	5-8	142	648	0.22	PASS	
	8-12	-187	-1102	0.17	PASS	
	12-14	224	648	0.35	PASS	
	B-1	0	-	0.00	-	Vertical Members
	F-5	94	338	0.28	PASS	
	H-7	0	-	0.00	-	
	L-11	0	-	0.00	-	
0	A-2	-372	-853	0.44	PASS	Inclined Members
1	F-6	-183	-506	0.36	PASS	
	E-5	-182	-590	0.31	PASS	
0	E-8	-405	-658	0.61	PASS	
0	K-12	-443	-695	0.64	PASS	
Bearing Areas Nodes at ⇉	A	330	772	0.43	PASS	1
	E	330	772	0.43	PASS	
	K	330	772	0.43	PASS	
	2	330	998	0.33	PASS	2
	6	94	285	0.33	PASS	
	8	236	755	0.31	PASS	
	12	165	528	0.31	PASS	

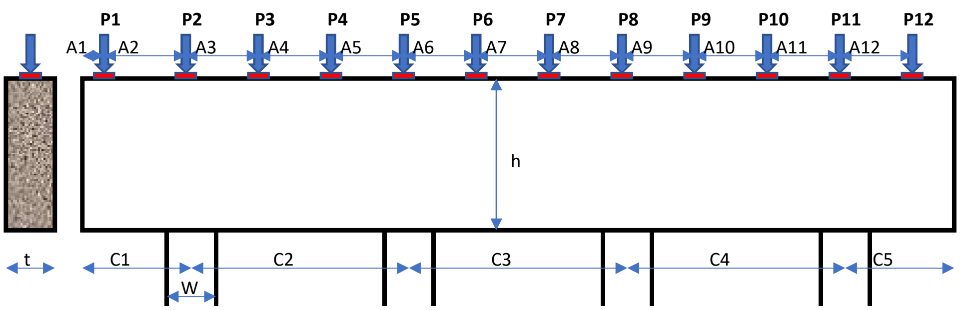
Re-Generate Output Model

Bridge Details:

Bridge Name:			
SFN Number:			
PID No.:			

1. Total Number of Columns (Piers)	4	Asymmetrical

2. Generate



Note: Input for Section 3 and Section 4 is based on the above-generated sketch. The loads shown in the above sketch are not the actual loads; these are shown for representation only.

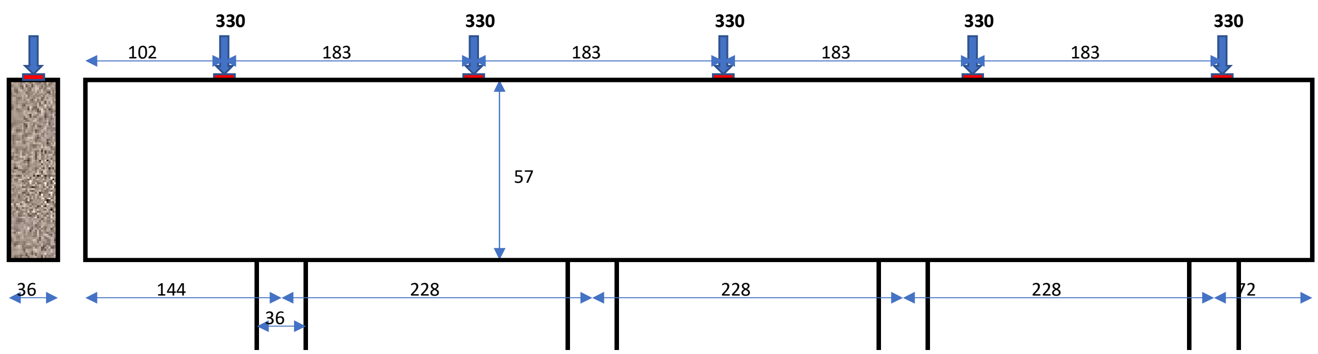
3. Geometry Details			
Distance from start of the pier cap to center of first column (C1)	12 ft	0 in	144.0 in
Distance from center of first column to center of second column (C2)	19 ft	0 in	228.0 in
Distance from center of second column to center of third column (C3)	19 ft	0 in	228.0 in
Distance from center of third column to center of fourth pier cap (C4)	19 ft	0 in	228.0 in
Distance from center of fourth column to the end of the pier cap (C4)	6 ft	0 in	72.0 in
Column width (W)	36 in	Circular	
Depth of pier cap (h)	57 in		
Thickness of pier cap (t)	36 in		

4. Factored Loads and their Position			
Distance of First Load from the Edge of Pier Cap	8 ft	6.0 in	102.0 in
Spacing Between the Girders	15 ft	3.0 in	183.0 in
Factored Load	330 k		

Generate Load Table

Factored Load		***Distance***			
P1	330 k	8 ft	6.0 in	102.0 in	A1
P2	0 k	0 ft	0.0 in	0.0 in	A2
P3	330 k	15 ft	3.0 in	183.0 in	A3
P4	0 k	0 ft	0.0 in	0.0 in	A4
P5	0 k	0 ft	0.0 in	0.0 in	A5
P6	330 k	15 ft	3.0 in	183.0 in	A6
P7	0 k	0 ft	0.0 in	0.0 in	A7
P8	0 k	0 ft	0.0 in	0.0 in	A8
P9	330 k	15 ft	3.0 in	183.0 in	A9
P10	0 k	0 ft	0.0 in	0.0 in	A10
P11	330 k	15 ft	3.0 in	183.0 in	A11
P12	0 k	0 ft	0.0 in	0.0 in	A12

5. Generate

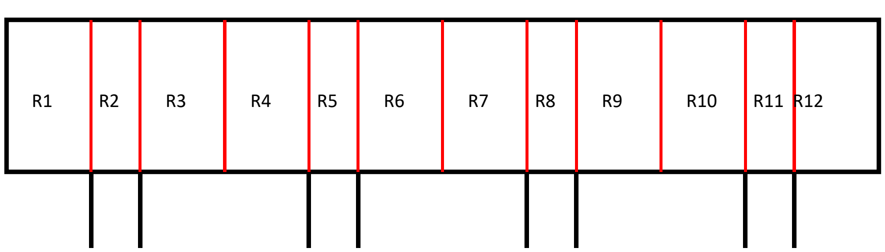


6. Check whether the Pier Cap is Deep			
Region	***Shear span (a)***	***a/d ratio:***	***Result***
R1	37.0 in	0.72	Deep Region
R2	0.0 in	0.00	Zero Region
R3	128.0 in	2.49	Slender Region
R4	78.3 in	1.53	Deep Region
R5	0.0 in	0.00	Zero Region
R6	87 in	1.69	Deep Region
R7	120 in	2.35	Slender Region
R8	0 in	0.00	Zero Region
R9	45 in	0.87	Deep Region
R10	162 in	3.16	Slender Region
R11	3 in	0.05	Deep Region
R12	0 in	0.00	Zero Region

This pier cap is deep.
Please continue with Section 7.

7. Material Properties	
Concrete strength (f'_c)	4.00 ksi
Rebar yield strength (f_y)	60.0 ksi
Diameter of biggest rebar (d_b)	1.00 in
Enter the clear cover	2.0 in
Stirrup yield strength(f_y)	60.0 ksi
Stirrup bar area	0.31 in^2

8. Resistance Factors Used	
For concrete	0.7
For longitudinal rebars	0.9
For stirrup	0.9
CCC v-factor for bearing and back face	0.85
CCT v-factor for bearing and back face	0.7
CTT v-factor for bearing and back face	0.65



9. Reinforcement Details

9A. Longitudinal Reinforcement

Region	Top Steel (in^2, in)		Bottom Steel (in^2, in)	
	Total Area (A_t)	Centroid (C_t)	Total Area (A_b)	Centroid (C_b)
R1	12	5	12	5
R2	12	5	12	5
R3	12	5	12	5
R4	12	5	12	5
R5	12	5	12	5
R6	12	5	12	5
R7	12	5	12	5
R8	12	5	12	5
R9	12	5	12	5
R10	12	5	12	5
R11	12	5	12	5
R12	12	5	12	5

9B. Transverse Reinforcement

Region	No. of Legs	Stirrup Spacing
R1	4	18 in
R2	4	18 in
R3	4	18 in
R4	4	18 in
R5	4	18 in
R6	4	18 in
R7	4	18 in
R8	4	18 in
R9	4	18 in
R10	4	18 in
R11	4	18 in
R12	4	18 in

9C. Min Horizontal Crack Control Reinforcement

Code Required Crack Control Reinforcement	0.30%
Crack Control Rebar Area (in^2)	0.31
Spacing (in)	9.0
No of layers of Crack Control Rebars	2
Crack Control Reinforcement	**0.19%**

10. Base Plate Dimensions

Base plate length parallel to the pier cap (L_b)	16.0 in
Base plate width perpendicular to the pier cap (W_b)	21.0 in

11. Reinforcement Development

Horizontal length available (L_d)	**110 in**

Top Tension Bars	
Enter the diameter of the top longitudinal bar:	1.00 in
Enter the length of the hook provided:	30 in
Basic development length	**19 in**

It qualifies for 90° hook.

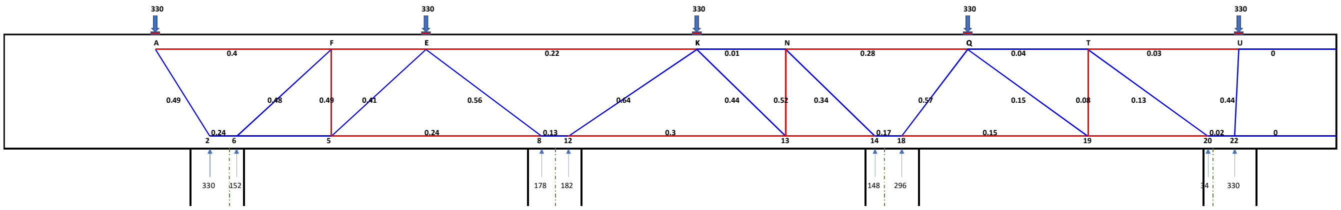
Modification Factor		
1. Are bars epoxy coated?	Yes	**1.2**
2. Is the side cover for No. 11 bar and smaller, normal to the plane of hook, is not less than 2.5 in, and 90° hook, cover on bar extension beyond hook not less than 2.0 in?	No	**1**

Required development length	**23 in**
Available development length (L_d)	**110 in**

Reinforcement Capacity Multiplier:	**1.00**

Analysis Output

12. Generate Output Model



Note: The above figure shows the output model with Utilization Ratio along with the member which are color coded. The node numbers are also printed for every node. This output model is based on below calculation details.

13. Strut and Tie Output Summary

STM Members

Input 0 for "Do not use Tie"
Input 1 for "Use Tie"
Input Your Option Down Here
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Tie Option	Summary					
	Member Code	*Force (k)*	*Capacity (k)*	*Utilization Ratio*	*Result*	
	A-F	260	648	0.40	PASS	Top Members
	E-K	142	648	0.22	PASS	
	K-N	-6	-1102	0.01	PASS	
	Q-T	-40	-1102	0.04	PASS	
	U-W	0	648	0.00	-	
	2-6	-260	-1102	0.24	PASS	Bottom Members
	5-8	153	648	0.24	PASS	
	8-12	-142	-1102	0.13	PASS	
	12-13	195	648	0.30	PASS	
	14-18	-183	-1102	0.17	PASS	
	18-19	100	648	0.15	PASS	
	20-22	-19	-1102	0.02	PASS	
	22-24	0	648	0.00	-	
	B-1	0	-	0.00	-	Vertical Members
	F-5	152	313	0.49	PASS	
	H-7	0	-	0.00	-	
	L-11	0	-	0.00	-	
	N-13	148	285	0.52	PASS	
	R-17	0	-	0.00	-	
	T-19	34	441	0.08	PASS	
	V-21	0	-	0.00	-	
0	A-2	-420	-851	0.49	PASS	Inclined Members
1	F-6	-256	-530	0.48	PASS	
	E-5	-257	-633	0.41	PASS	
0	E-8	-345	-620	0.56	PASS	
0	K-12	-383	-599	0.64	PASS	
1	K-13	-240	-546	0.44	PASS	
	N-14	-240	-711	0.34	PASS	
0	Q-18	-408	-721	0.57	PASS	
1	Q-19	-69	-474	0.15	PASS	
	T-20	-69	-542	0.13	PASS	
0	U-22	-331	-751	0.44	PASS	
Bearing Areas Nodes at ⇉	A	330	772	0.43	PASS	1
	E	330	772	0.43	PASS	
	K	330	772	0.43	PASS	
	Q	330	772	0.43	PASS	
	U	330	772	0.43	PASS	
	2	330	879	0.38	PASS	2
	6	152	404	0.38	PASS	
	8	178	634	0.28	PASS	
	12	182	648	0.28	PASS	
	14	148	428	0.35	PASS	
	18	296	855	0.35	PASS	
	20	34	121	0.28	PASS	
	22	330	1161	0.28	PASS	

Re-Generate Output Model