VIRGINIA POLYTECHNIC INSTITUTE
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The Charles E. Via, Jr. Department
of Civil and Environmental Engineering
Blacksburg, VA 24061

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Assessment of Shear Connection Ductility in Composite Beams – Implications on the U.S. Design Practice

By

J.R. Ubejd Mujagic
Structural Engineering Consultant, Atlanta, GA

W. Samuel Easterling
Virginia Tech, Blacksburg, VA

John S. Bennett
Uzun+Case Engineers, LLC, Atlanta, GA

Amit H. Varma
Purdue University, West Lafayette, IN

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Assessment of Shear Connection Ductility in Composite Beams – Implications on the U.S. Design Practice

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W.S. Easterling, Virginia Tech, Blacksburg, VA
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1. Background

Shear connection at the interface of a concrete slab and supporting steel members is an assembly consisting of the connector, typically a steel headed stud anchor, and the surrounding concrete with a specific deck flute geometry. Shear connection deforms when subjected to shear at the interface. Its ability to deform without fracturing is known as slip capacity or the ductility of shear connection. It is important to note that the term ductility does not merely relate to the ductility of the connector itself, but to the ductility of the overall shear connection assembly. For example, a shear connection failing by ductile bending and subsequent fracture of stud metal, is between 0.25 and 0.30 in. (Oehlers & Coughlan 1986). However, examination of test data provided by Rambo-Roddenberry (2002) and Lyons et al. (1994) show that the shear connection with the same connector embedded in a slender concrete slab rib, whose fracture controls the strength of the shear connection, will possess only a fraction of this slip capacity. The same data also illustrates a higher slip capacity in shear connections where studs are located in weak position compared to the strong position. Slip capacity is also affected by the concrete compressive strength and stud diameter (Oehlers & Coughlan 1986).

Rigid plastic analysis of a composite section is the most typical manner for establishing the member strength. It assumes sufficiently ductile steel and concrete components capable of developing a fully plastic stress block across the depth of the composite section. This analysis also assumes both a sufficiently ductile shear connection, allowing for the shear at the interface to be evenly shared among the connectors located between the points of zero and maximum moment, and an infinite stiffness under applied shear at the interface, allowing no discontinuity in the strain diagram at the interface of concrete slab and steel beam. Although these two assumptions are in direct conflict, slip at the interface is typically comparatively small in terms of effect on the computed flexural strength of the composite section. Rigid plastic analysis of a composite section is illustrated in Figure 1 and by Equation 1 for the case where plastic neutral axis resides within the steel section.

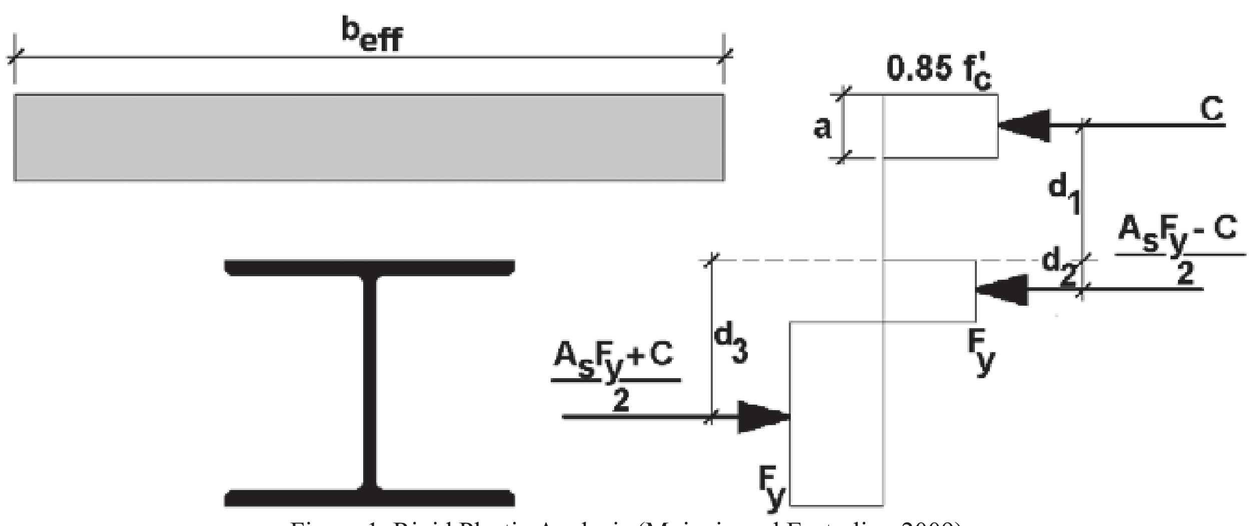

Figure 1 Rigid Plastic Analysis (Mujagic and Easterling 2009)

$$\phi M_n = \phi[0.5(A_sF_y + C)(d_3 - d_2) + C(d_1 + d_2)] \quad \text{(Eq. 1)}$$

In Figure 1 and Equation 1, C is the lesser of A_sF_y, $0.85f'_cA_c$ and $\sum Q_n$, where $\sum Q_n$ is the total nominal shear connection strength provided between the points of maximum and zero moments in a composite member. A_sF_y designates the axial yield strength of the steel member, The term $0.85f'_cA_c$ represents the plastic axial strength of the concrete slab, where $A_c = b_{eff}(t_s-h_r)$. Furthermore, A_s is the cross-sectional area of the steel member, F_y is the specified minimum yield stress of the steel member, f'_c is the concrete compressive strength of the slab, b_{eff} is the effective slab width as defined in ANSI/AISC 360-10, t_s is the total slab thickness and h_r is the deck rib height. The strength reduction factor, ϕ, is 0.90, as defined in ANSI/AISC 360-10.

In partially composite beams, especially when relatively few connectors are provided, the propensity of the concrete slab to displace horizontally relative to the steel beam at the member ends can become significant and generally escalate with increasing span lengths and decreasing number of connectors at the interface. When this slip exceeds the ductility of the shear connection, shear at the interface may fail to evenly distribute among the connectors between the points of zero and maximum moment, causing the progressive failure of shear connection at a moment strength less than that predicted by the rigid plastic analysis of the section. A laboratory manifestation of this phenomenon in the case of a composite steel-concrete with insufficiently ductile shear connection is illustrated by Mujagic et al. (2010), along with a comparative case of a member with a sufficiently ductile shear connection. For the convenience of the reader, these are graphically reproduced in Figures 2 and 3. Specifically, Figure 2 illustrates a fully composite member where the shear connection possesses adequate strength and ductility to accommodate the redistribution of longitudinal shear at the interface of the steel member and the concrete slab and the consequent yielding of the cross-section. This is characterized, as evident from the figure, by a relatively uniform measured slip along the member span. Figure 3 illustrates a condition whereby a member, nominally configured as a fully composite, ended up failing at loads far below those that were predicted using rigid-plastic analysis of the composite section. The slip distribution curve is in this case linear, as can be seen in the Figure. It must be noted that the presence of a linear slip-span diagram does not necessarily always indicate a non-ductile shear connection. Depending on the influence of other considerations and variables, such as distribution of connectors along the span, length of span, load-slip response of an individual shear connection, etc., a member with sufficient shear connection ductility could exhibit an essentially linear slip-span relationship. However, a linear slip-span diagram coupled with a capacity far below that predicted by the rigid plastic analysis, indicates an insufficient ductility of shear connection.

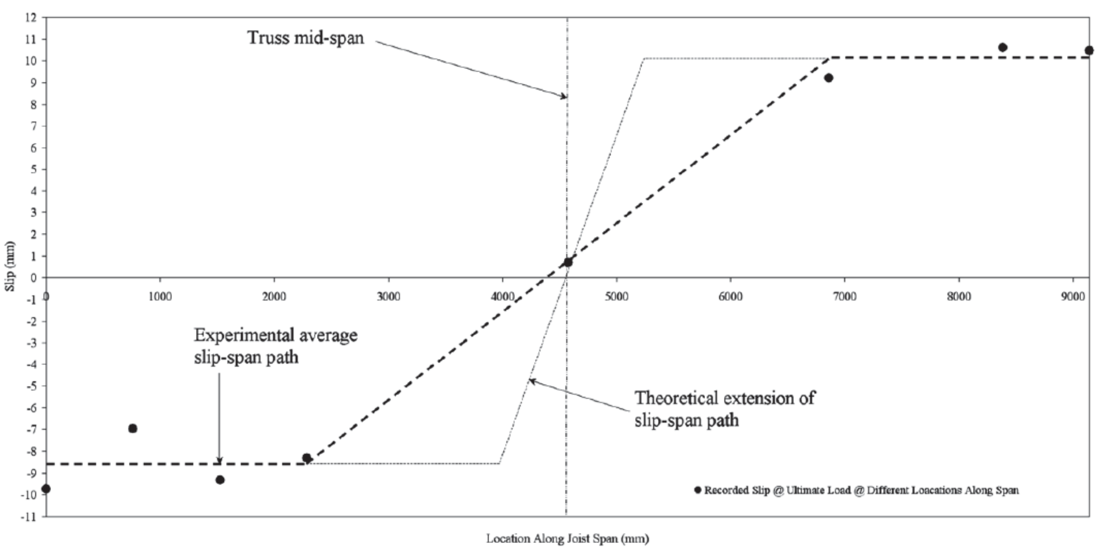

Figure 2 Slip Distribution in Member with Sufficiently Ductile Shear Connection (Mujagic et al. 2010)

Several methods exist in addressing the ductility demand at the interface of the concrete slab and steel beam. They generally fall into two groups. First, the effect of shear at the interface can be taken into account directly in the determination of member strength through modeling of the interface slip. The complexity of such an analysis varies greatly based upon whether all components of the composite beams are idealized as linearly elastic (Newmark 1951; Robinson & Naraine 1988; Viest 1997), or considered using a nonlinear analysis, by capturing inelastic behavior of a partially yielded section and non-linear behavior of the shear connection along the span (Salari, et al. 1998; Salari and Spacone 2001; Zona and Ranzi 2014). Various indirect analytical models have also been proposed. Such models aim to provide convenient computational models suitable for routine design use by either idealizing various components of the composite beam as fully elastic or fully plastic and capturing most dominant elements driving the shear connection ductility demand (Sved and Oehlers 1995) or by parametrically relating the results of rigorous non-linear finite element analyses to the most critical design properties affecting shear connection ductility through simple algebraic relationships (Johnson and Molenstra 1991).

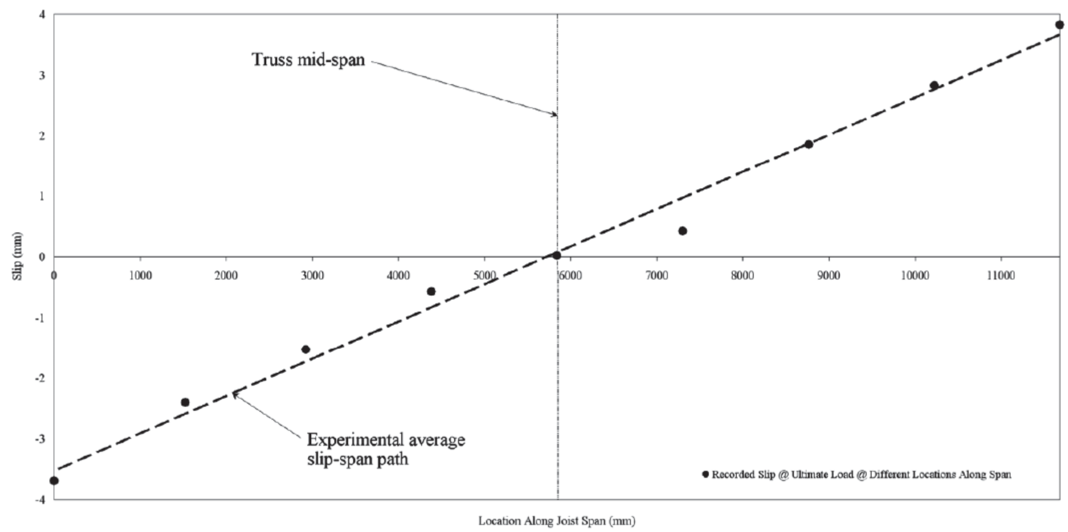

Figure 3 Slip Distribution in a Member with Insufficiently Ductile Shear Connection (Mujagic et al. 2010)

The second set of methods aimed at addressing ductility revolves around setting a lower limit on the degree of the composite action such that the applicability of the rigid plastic analysis model is preserved. Most such limits, as is the case with the requirements of EN 1994-1-1 (CEN 2004), are expressed as a function of member length, recognizing it as the primary determinant in affecting the required shear connection ductility. In some cases, primarily for the sake of simplicity, an absolute lower limit on the degree of composite action is set. Such a limit, typically ranging from 40-50% (Selden et al. 2015), are stipulated on the basis of some assumption of the worst-case practical scenarios of load and span but can be overly conservative for shorter members.

When using degree of composite action as the means of controlling the ductility demand at the interface of concrete slab and steel beam in a composite member, it is important to correctly define the term. In this context, the degree of composite action is the ratio of composite connection shear strength between the points of zero and maximum moment to the lesser of A_sF_y and $0.85f'_cb_{eff}(t_s-h_r)$.

It has also been shown that the computed flexural strength of a composite section is significantly more sensitive to the statistical distribution associated with shear connection at lower degrees of composite action (Mujagic and Easterling 2009). To this end, the degree of shear connection of 50% or more could prevent a configuration of the composite member resulting in a lower reliability index than implied by the Specification. Although this issue is primarily related to member reliability, the consequence of a higher degree of shear connection provided has the consequence of reducing the ductility demand on the shear connection.

As noted in the preceding text, the consideration of ductility demand in composite beams can come in the form of a number of different approaches of varying degrees of complexity. Configurations of composite beams as designed in routine practice depend on strength and serviceability requirements, detailing rules, construction sequence, fabrication logistics, fire rating requirements, as well as various other considerations related to standard practice. Many of these elements will directly or indirectly affect the ductility performance of the shear connection. Consequently, the parameters controlling the ductility of shear connection in a beam may in fact not govern the beam design. On the other hand, a beam configuration governed by a design consideration other than strength, such as serviceability, may not be automatically assumed as insensitive to shear connection ductility, as strength predicted by rigid plastic analysis of the composite section could in fact considerably overestimate the actual available member strength in configurations with insufficient shear connection ductility. For this reason, it is not possible to assess the sensitivity of practically encountered composite beam configurations to shear connection ductility by considering the strength parameters alone. Instead, it is necessary to perform an extensive survey of the entire envelope of practically occurring composite beams in the context of the overall member and building design and construction.

2. Analysis

The purpose of this study is to perform a realistic and practically meaningful assessment of ductility demand in shear connection through consideration of a comprehensive database of practically occurring composite beams and girders meeting the requirements of ANSI/AISC 360-10 (AISC 2010), loading criteria of 2015 IBC (ICC 2015), and prevailing construction, detailing and fabrication requirements typically encountered in the American practice. The goal of the study is to identify framing and loading composite beam configurations that exhibit significant disconnects between the available and required ductility of shear connection and to propose prescriptive limits that would preclude such configurations from occurring in practice. To do so, it is first necessary to identify the appropriate analysis technique and to identify the parameters with the most influence on the ductility demand at the interface of concrete slab and the steel beam in a composite member. Furthermore, as an alternative, the study seeks to propose an approach whereby a designer could evaluate the available and required shear connection ductility directly in the context of the application of ANSI/AISC 360-10 requirements in design of composite beams.

2.1 Approach

The mixed analysis approach by Oehlers and Sved was used in this study as the primary method of analysis. It rests upon observation that yielding in a composite beam at the ultimate load capacity defined by its rigid plastic strength is confined to about 15% of the steel beam volume, thus preserving the validity of the Bernoulli-Euler beam relationships relating to strain, member curvature and deformation over most of the span. Thereby, the behavior of the composite beam could be idealized as comprising linear-elastic slab and beam components and a fully plastic shear connection, where each shear connector resists the same portion of the longitudinal shear at the interface. The mixed analysis approach is an extension of the classical approach by Newmark et al., which treats all components of the composite beam, including shear connection, as linearly elastic, which is incommensurate with the assumptions used in design of composite beams with ductile shear connection at ultimate factored load, with full section plasticity. Also, it is a mathematically exact formulation, which even considers the tension in shear connectors due to relative difference in flexibility between the concrete slab and the steel beam in the composite beam. As such, it is too numerically complex for a routine application. The same could be stated for explicit non-linear simulations referenced in the preceding text.

The mixed analysis approach, with the above described simplified behavioral lends itself as an appropriate method for routine use given its manageable computational structure, as well as considering it intuitive and easily understandable derivation. The detailed derivation of the approach is presented by Oehlers and Sved (1995). The following summarizes the computational steps relative thereto, incorporating the appropriate modifications necessary for application to beams with slabs on steel decks with flutes parallel and perpendicular to the steel member. Also, the procedure is modified as needed to make it conducive to use in the context of ANSI/AISC 360-10.

(a) Establishment of the member design, geometric, strength and stiffness properties of individual constitutive components of the composite beam (e.g., f'_c, F_y, W shape designation, formed deck profile, strength reduction factors, etc.).
(b) Calculation of the required moment strength, $M_r = M_u$.
(c) Determination the available moment strength, $\phi M_{n,s}$, of the fully braced bare steel member per ANSI/AISC 360-10 Chapter F.
(d) Computation of the available moment strength of the composite member, $\phi M_{n,RPA}$, based on rigid plastic analysis per ANSI/AISC 360-10 Chapter I, as illustrated by Equation 1 and in Figure 1.
(e) Computation stiffness parameters K_1 and K_2 as follows:

$$K_1 = (h_c + h_s)(E_cI_c + E_sI_s)^{-1} \quad \text{(Eq. 2)}$$

$$K_2 = h_c^2(E_cI_c + E_sI_s)^{-1} + (E_cA_c)^{-1} + (E_sA_s)^{-1} \quad \text{(Eq. 3)}$$

Where the variables not previous defined are as follows:

h_c = $t_c/2 + h_r$ for slabs on formed steel deck with flutes perpendicular to the beam span
= for slabs on formed steel deck with flutes parallel to the beam span, this is the distance from the top of steel beam to the geometric centroid of the slab
= $t_s/2$ for solid slabs

t_c = $t_s - h_r$

h_s = distance from the top of steel beam section to its geometric centroid
= half of beam depth for a vertically symmetric section such as a hot rolled I-shape beam

I_c = $b_{eff}t_c^3/12$ for slabs on formed deck with flutes perpendicular to the beam span
= for slabs on formed steel deck with flutes parallel to the beam span, this is the gross moment of inertia of the slab cross section over the width b_{eff}
= $b_{eff}t_s^3/12$ for solid slabs

A_c = $b_{eff}t_c$ for slabs on formed deck with flutes perpendicular to the beam span
= for slabs on formed steel deck with flutes parallel to the beam span, this is the gross moment of inertia of the slab cross section over the width b_{eff}
= $b_{eff}t_s$ for solid slabs

E_c = modulus of elasticity as defined by ANSI/AISC 360-10

(f) Compute available moment strength limited by the shear connection ductility, $\phi M_{n,sc}$, based on the following relationship:

$$S_n = K_1 \int_0^{L_s} M_u dx - K_2 \sum Q_n L_s \qquad \text{(Eq. 4)}$$

Where:

S_n = ductility (slip capacity) of the shear connection from test data
= 0.25 in. for shear connections meeting requirements of ANSI/AISC 360-10

L_s = shear span (i.e., beam length from the points of zero and maximum slip
= L/2 for simply supported beams under uniform load

Based on Eq. 4, the moment strength limited by stud fracture envelope can be developed for various specific configurations. Specifically, at the mid-span of a uniformly loaded beam:

$$\phi M_{n,sc} = 0.90(3S_n + 0.75\Sigma Q_n LK_2)/(LK_1) \qquad \text{(Eq. 5)}$$

Similarly, at the mid-span of a girder with a beam, or beams, connecting at mid-span:

$$\phi M_{n,sc} = 0.90(4S_n + \Sigma Q_n LK_2)/(LK_1) \qquad \text{(Eq. 6)}$$

At 1/3-span points and at mid-span of a girder with beams connection at 1/3- and 2/3-span points:

$$\phi M_{n,sc} = 0.90(6S_n + \Sigma Q_n LK_2)/(LK_1) \qquad \text{(Eq. 7)}$$

At mid-span of a girder with beams connection at 1/4-, 1/2- and 3/4-span points:

$$\phi M_{n,sc} = 0.90(3.2S_n + 0.8\Sigma Q_n LK_2)/(LK_1) \qquad \text{(Eq. 8)}$$

Finally, at 1/4- and 3/4- span points of a girder with beams connection at 1/4-, 1/2- and 3/4-span points:

$$\phi M_{n,sc} = 0.90(8S_n + 0.8\Sigma Q_n LK_2)/(LK_1) \qquad \text{(Eq. 9)}$$

Where:

ϕ = strength reduction factor = 0.9

$M_{n,sc}$ = moment strength limited by the shear connection fracture envelope

(g) Compute the available flexural strength of the member, ϕM_n, as follows and establish whether $\phi M_n \geq M_r$:

$$\phi M_n = \max(\phi M_{n,sc}, \phi M_{n,RPA}) \qquad \text{(Eq. 10)}$$

The practical implication and significance of the mixed analysis approach is illustrated in the following example of a 60-ft long composite beam featuring a 7.5-in. thick normalweight concrete slab on Vulcraft 3VL formed steel deck and camber of 2.25 in. The beam loads, factored per the requirements of 2015 IBC entail the application of a reducible 100-psf live load and a superimposed dead load of 15 psf. The available strength is calculated using the provisions of ANSI/AISC 360-10, and the beam is configured to satisfy the live load deflection limit of L/360, the total deflection limit of L/240, and the pre-composite dead load deflection limit of L/200. Other than what is necessary to meet the preceding strength and serviceability criteria, no other minimum threshold for the degree of composite action is imposed. In this particular scenario, the composite beam configuration is optimized for the least-possible weight of the steel member, as is customary in practice, and all studs are placed in the strong position. This results in a W27x84 shape and the required moment of 1035 k-ft.

Figure 4 illustrates the strength envelope based on rigid plastic analysis whereby the available strength in kip-ft (vertical axis) is plotted against the degree of shear of connection in (horizontal axis). As can be seen, when the degree of shear connection is zero, $M_a = \phi M_n$ = 915 kip-ft (Fig. 7). At the degree of shear connection of 100%, ϕM_n is just short of 1800 kip-ft.

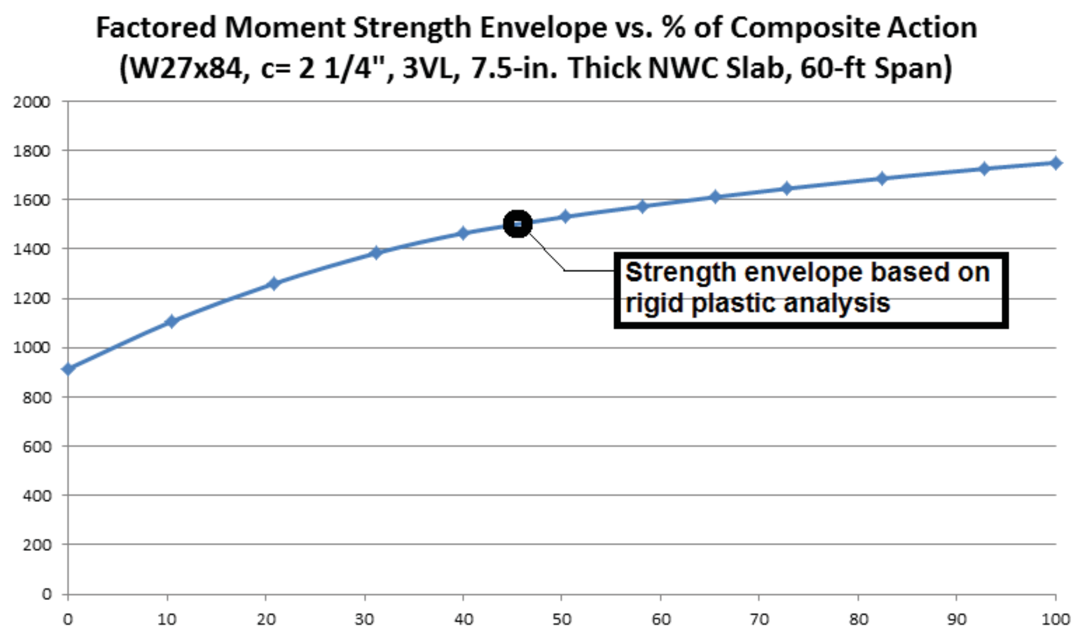

Figure 4 Strength Envelope Based on Rigid Plastic Analysis

Next, Figure 5 shows that the design warrants the degree of shear connection of 17.4%, which corresponds to (20) ¾-in. dia. headed shear studs, or 10 per shear spans, which in turn results to $\sum Q_n$ of 215.4 kips per shear span. In this particular case, the shear connection is governed by the ANSI/AISC 360-10 maximum stud spacing limitation of 36 in. With this, based on rigid plastic analysis, $\phi M_{n,RPA}$ = 1212 kip-ft (Point A in Fig. 5) > 1035 kip-ft (Point E in Fig. 5), which implies that the design for strength is satisfactory, and per ANSI/AISC 360-10, $\phi M_{n,RPA} = \phi M_n = M_a$. However, if one further incorporates the limitation of moment strength by considering the limited shear connection ductility, the moment strength envelope shown in Figure 6 results. Therein, the shear connection ductility of 0.26 in. was obtained by application of the Oehlers and Coughlan criteria shown as Equation 11. Further background on determination of slip capacity (shear connection ductility) as it relates to this study is provided in Section 2.2.

$$S_n = d_s(0.41 - 0.021f'_c) \quad \text{(Eq. 11)}$$

Where:

d_s = stud shank diameter (in.)

f'_c = concrete compressive strength, ksi

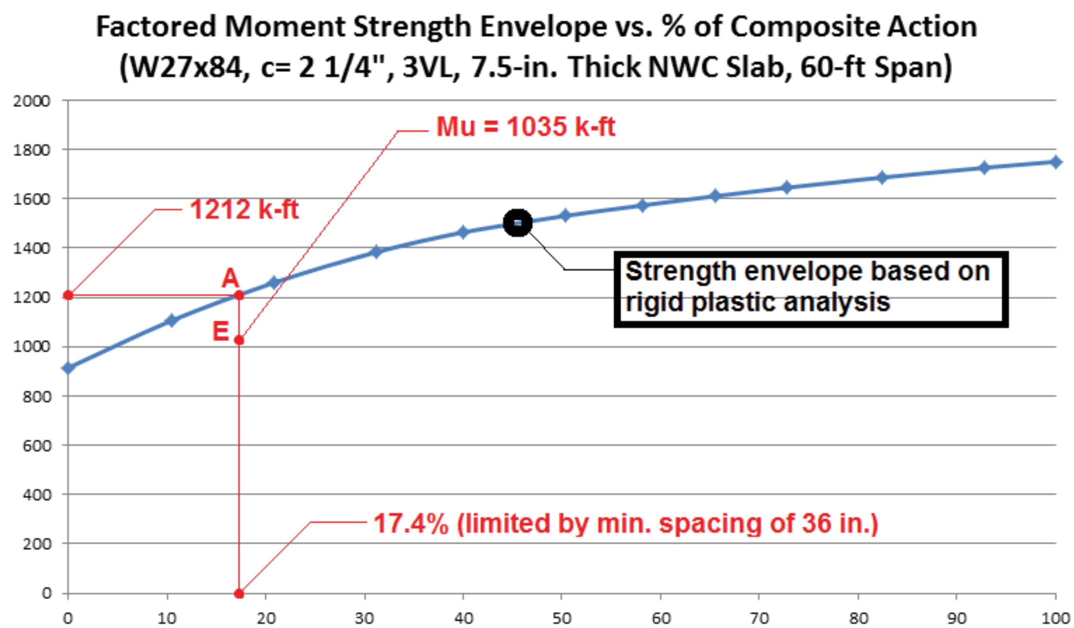

Figure 5 Required Strength, M_u, and the Available Strength Envelope based on Rigid Plastic Analysis

As can be seen, the addition of the strength envelope based on the shear connection ductility in this case considerably truncates the envelope generated by rigid plastic analysis. Therefore, the actual available strength is considerably lower than that predicted by rigid plastic analysis, as in this case, for this particular beam geometry and loading requirements the ductility demand at the interface of the concrete slab and the steel beam to justify the rigid plastic analysis is considerably higher than what can be afforded. Specifically, for the degree of composite action of 17.4%, $\phi M_{n,sc}$ = 700 kip-ft (Point G in Figure 6), which is considerably less than the M_u = 1035 kip-ft.

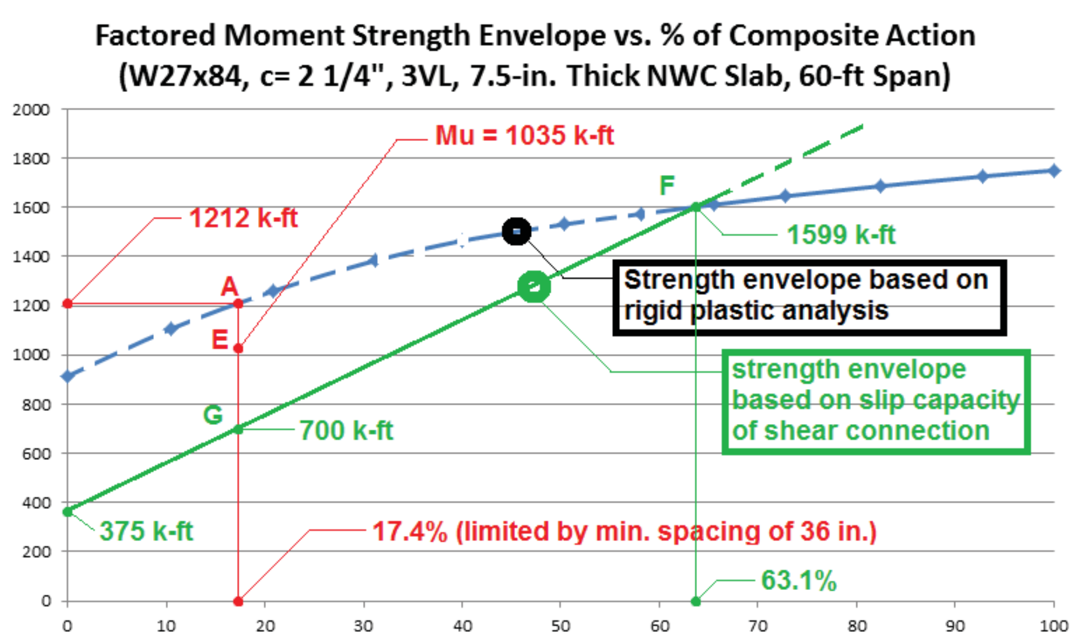

Figure 6 Available Strength Based on Rigid Plastic and Shear Connection Fracture Envelopes vs. Required Strength

Furthermore, Figure 6 illustrates that the rigid plastic analysis and slip capacity envelopes intersect at Point F. This point, in this particular case, corresponds to the degree of shear connection of 63.1%. From this it follows that the rigid plastic analysis cannot be used to for this particular beam to correctly calculate the moment strength of the composite section unless the degree of shear connection were at least 63.1%. Another observation from Figure 6 is that the for the degree of shear of 17.4% for this particular beam results in a moment strength of less than what is provided by the fully plastic bare steel section, which corresponds to the rigid plastic curve value at the degree of shear connection of zero. The physical manifestation of this phenomenon would be that the bare beam design is based upon a fully plastic section, whereas the moment strength envelope based on limited slip capacity allows for the formation of only limited plastification of the steel section and therefore a lower overall strength at a very low degree of shear connection. However, once the shear connection strength is exhausted and subsequently lost due to a limited slip capacity, and a high slip demand, the section will proceed towards the development of a fully plastic non-composite section. The adjusted strength envelope is reflected in Figure 7. Thereby, for this particular beam considering all three components of the strength envelope (i.e., rigid plastic, stud fracture and bare beam), $\phi M_n = 915$ kip-ft, as identified by Point B. Clearly, this is still lower than M_u of 1035 kip-ft (Point E in Figure 7), thus rendering the beam design unsatisfactory, despite of sufficient strength predicted by the rigid plastic analysis.

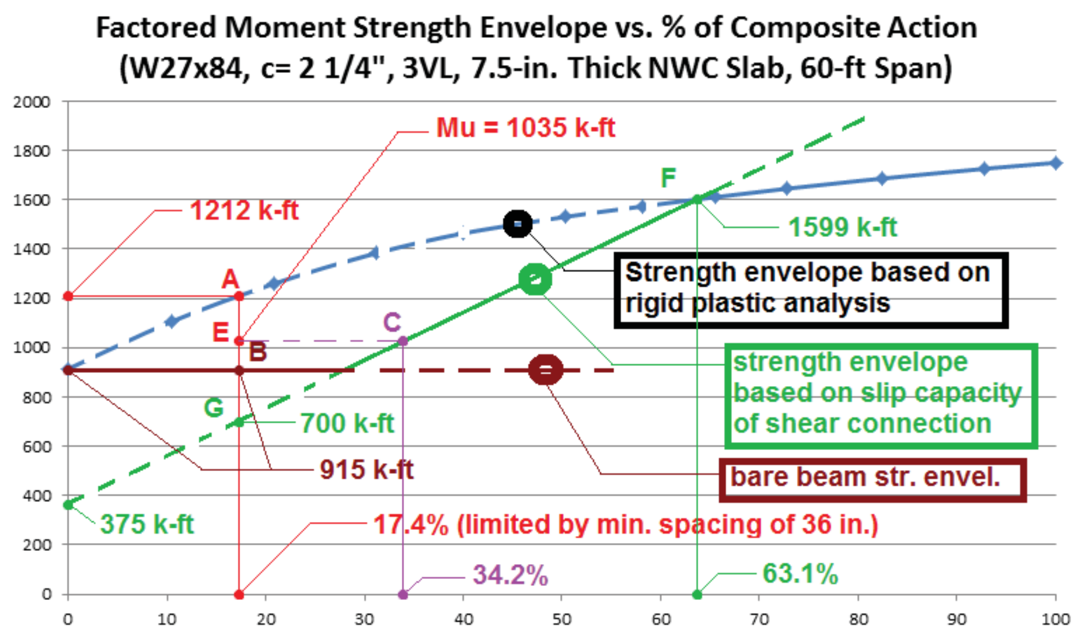

Figure 7 Governing Strength Envelope Incorporating the Bare Beam Strength vs. Required Strength

Figure 7 provides contours of possible approaches for taking into account the shear connection ductility in the design. First, the user could apply the mixed analysis approach directly by applying the above laid out steps (a) through (g) of the procedure, explicitly identifying the three distinct components of the moment strength envelope for a known shear connection ductility and subsequently establishing the relationship of the required moment strength, the selected degree of composite action and the governing strength envelope consisting of three components, as laid out above. Obviously, this would in many cases involve a departure from the rigid plastic analysis upon which ANSI/AISC 360 provisions are based, and consequently an additional computational complexity and considerations. Second option is to limit the degree of shear connection to a minimum value that would preserve the validity of rigid plastic analysis. In this scenario of this case study this would be 63.1%. The difficulty with this approach stems from a couple of practical considerations. Specifically, this percentage varies based on particular configuration of composite beam geometry and loads and no unique solution is possible without simplification that invariably penalizes some classes and configurations of composite beams. Another consideration entails an additional source of an overly conservative design in terms of what degree of shear connection does a particular beam actually require. For example, in this case, the degree of shear connection of 17.4% results in a satisfactory design for serviceability. The degree of shear connection of 34.2% satisfies both the strength and serviceability requirements and results in moment strength equal to the required strength of 1035 kip-ft. However, to preserve the validity of the rigid plastic analysis, an additional of nearly 30% in the degree of composite action would be required, corresponding in nearly 600 kip-ft of an additional moment capacity in excess of what is actually required to meet the design requirements. Clearly, this is economically unviable. Third option would be to identify the degree of composite action, based on various parameters that dominantly affect the ductility demand, such as span length, loads and member stiffness, at which the practically occurring beams, otherwise satisfying all pertinent serviceability and constructability requirements, would at the minimum achieve the satisfactory moment strength by virtue of a prescriptive lower limit on minimum degree of shear connection, even if the strength were to be calculated using rigid plastic analysis in all cases. For example, in this particular case study, if there existed a codified lower limit on the degree of composite action of 34%, the user would, using rigid plastic analysis, compute an available strength of approximately 1400 kip-ft, as can be seen from Figure 7. Strictly speaking, this would be an incorrectly computed strength. However, the resulting solution would be safe for the prescribed loads via the stipulated limit for the minimum degree of composite action, without the explicit requirement for additional computational burden past the usual rigid plastic analysis. This study attempts to arrive at such prescriptive limits based on consideration of an envelope of practically occurring composite beam cases.

The validation of mixed analysis approach came through its comparison to the parametric study approach by Johnson and Molestra (1991). Oehlers and Sved found a very good correlation at lower degrees of composite action, which is of particular interest to this study. The significant divergence between the two methods was observed at a higher degree of composite action of 75%. This was explained by the authors by the presence of significant plastification of the member at higher degrees of composite action, which departs from the key assumptions upon which the mixed analysis approach is based. This is not of particular interest or concern to this study, which focuses on lower degrees of composite action where the likely disconnects between the required and the available shear connection ductility are likely to occur.

2.2 Assumptions and Parameters of the Analysis

The following summarizes the geometric and load parameters of the parametric analysis performed in this study utilizing the mixed analysis approach:

- Vulcraft 2VL and 3VL composite deck profiles with 3 ¼-in. thick lightweight (110 lb/ft^3) and 4 ½-in. thick normalweight (150 lb/ft^3),
  concrete topping,
- Load scenarios involving: (a) 100 psf reducible live load with 15 psf superimposed dead load, and (b) 50 psf reducible live load with 15 psf superimposed dead load,
- Spans ranging from 20 to 70 ft in increments of 5 ft,
- Concrete compressive strengths, f'_c, of 3 and 4 ksi,
- Strong stud position in all cases,
- Design and detailing requirements of ANSI/AISC 360-10,
- Interior beam and girder members (i.e., equal bay geometry on both sides of the considered member),
- Live load deflection limit of L/360, the total deflection limit of L/240, and the pre-composite dead load deflection limit of L/200; in post-composite state, the moment of inertia of the composite section was computed as $0.75I_{equiv}$, where I_{equiv} is the equivalent moment of inertia, as discussed in the Commentary to ANSI/AISC 360-10.
- The design meets the requirements of AISC Design Guide 11 (AISC 1997) floor vibration criteria for paper offices, neglecting the effect of floor width, B, and length, L, as defined in AISC Design Guide 11.
- Where camber is necessary, the minimum camber of ¾ in. is used. Furthermore, beams shallower than 14" or those with the web thickness of ¼ in. or less were not cambered. Instead, when camber was warranted, by the design, the next larger and most efficient beam size was selected (e.g., W16x26 to replace a W14x22, but not W14x26). Finally, camber was set not to exceed 80% of the composite beam self-weight.
- No specific prescriptive minimum degree of composite action is imposed other than what is computationally required to satisfy the strength and serviceability requirements.

It is obvious from Oehlers and Sved (1995), as well as from steps (a) through (g) illustrated in Section 2.1, that the mixed analysis approach does not distinguish between pre-composite and post-composite loads in terms of the interface slip demand. This is a straightforward consideration when dealing with propped (shored) composite floor construction. However, it becomes somewhat more complex when considering the far more common unshored construction. Specifically, one could argue that prior to concrete hardening and the consequent onset of the composite coupling between the concrete slab and the steel beam, the ductility demand at the interface of the slab and beam is zero, which might appear intuitive from the sequence of loading and was a consideration in various other studies, such as the one by Zona and Ranzi (2014). However, the authors hold that the slip demand at the interface should be evaluated on the basis of the entire load, including the portion occurring prior to the onset of the composite coupling between the concrete slab and the steel beam, and this study is based on that hypothesis, based on two considerations.

First, the current design practice for strength based on rigid plastic analysis under the auspices of ANSI/AISC 360-10 involves two independent design checks:

1. Strength check at the pre-composite stage to establish that the available strength based on plastic flexural strength of the bare steel beam equals or exceeds the factored moment due to construction live loads and self-weight of concrete and the steel beam,
2. Strength check at the composite stage to establish that the strength of fully or partially composite beam flexural strength based on rigid plastic analysis equals or exceeds the factored moment due to service dead load, service live load and self-weight of concrete and the steel beam.

Evidently, the above design process neglects the cumulative nature of load application in conjunction with changes in member properties at concrete hardening. In other words, pre-composite loads consisting of the slab and the beam self-weight are computationally resisted by the composite beam strength that does not exist at the stage of these loads' occurrence. However, the propriety of this design methodology is supported both through further examination of composite beam mechanics by test data. Specifically, Figure 8 indicates possible stress conditions at the pre-composite stage. As can be seen, the actual stress in the beam under the applied pre-composite loads will very somewhere between a linear stress diagram in which the extreme fiber is still within the elastic stress range, and the fully plastic section. In all cases, however, it is clear that the neutral axis will remain at half-depth for any vertically symmetric section, regardless of which of the stress configurations from Figure 8 the section ultimately assumes under the applied pre-composite loads.

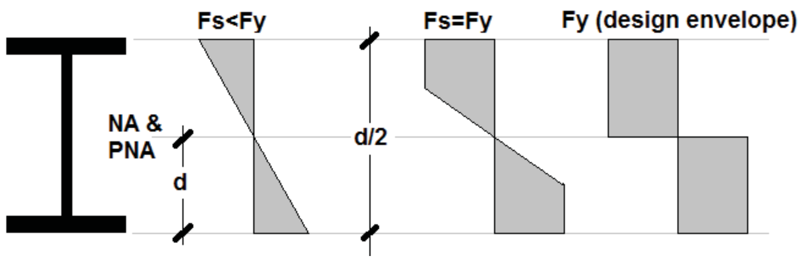

Figure 8 Beam Stress Scenarios at Pre-Composite Stage

As an example, the most critical case, the pre-composite section stress will assume the idealized shape of a fully plastic section, as shown on the right side of Figure 8. This would also represent the strength of the beam under the factored service loads if no shear connection was provided. As shear connection is added, the plastic neutral axis will gradually shift towards the top of the beam. Such a shift results in a significant reversal of stresses within the depth of the neutral axis shift. This reversal translates into the direct demand on the shear connection. For instance, the total stress reversal between the fully plastic pre-composite strength envelope illustrated in Figure 8 and the composite section stress configuration illustrated in Figure 1 is identified in Figure 9, which exacts a considerably higher demand on the shear connection than could be deduced by the difference between the total and pre-composite loads.

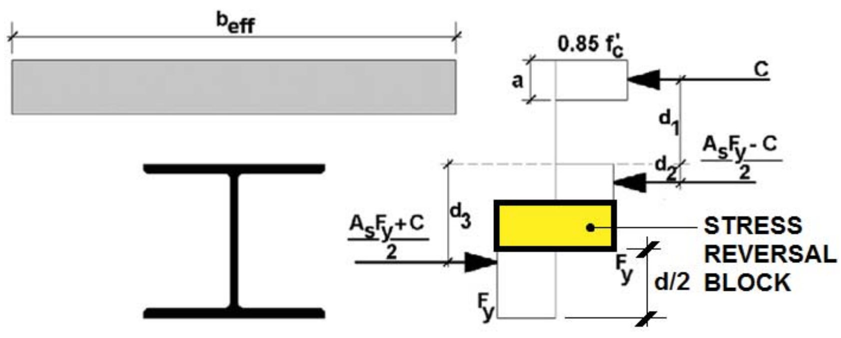

Figure 9 Stress Reversal Block in a Partially Composite Beam

Obviously, in a fully composite beam in which the plastic neutral axis rests above the steel section, the reversal between the strength envelopes of a fully composite beam so configured and the fully plastic steel section illustrated in Figure 8 will result in the demand on the shear connection at the interface equal to A_sF_y. Since the ductility demand is directly related to the force in the connectors, the ductility demand at the interface should be evaluated on the basis of total loads for both shored and unshored construction. The second consideration relates to the fact that the slip at interface causes discontinuity in the composite section strain diagram. While this discontinuity is not practically significant, it does contribute to the notion that the forces in shear connection at the interface are somewhat larger than can be predicted by the rigid plastic analysis of the composite section for any particular plastic moment strength. Finally, it should be noted that the rigid plastic analysis of composite beams is validated against tests under the assumption that the composite section resists the entire applied load, including the pre-composite thereof. Comparable predicted and tested strengths of full-scale tests, as well as the assessment of shear connection forces back-calculated from the results of the full-scale tests, support the notion that the plastic flexural strength of the composite section should be used to resist the moments due to entire load, including the pre-composite portion thereof. This is also the basis of the current design practice.

Shear connection ductility (slip capacity) can exhibit three distinct types of response. These are depicted in Figure 10. Specifically, the desirable response will involve the force-slip relationship exhibited in the left graph (Pattern A). Therein, the connection will either exhibit a deformation hardening response, or an essentially flat load-deformation response following the initial load-deformation proportionality. In some cases, one can observe a minor decline in sustained shear with increasing displacement, but this is practically inconsequential. The middle graph illustrates a deformation-softening response (Pattern B). Although the shear connection in such a scenario is often capable of undergoing large deformations, the maximum load cannot be maintained throughout the entire range of this deformation. As a result, this post-peak load deformation, albeit often significant in value, is not structurally useful. In this case, the, the ductility of shear connection would be the displacement at which the maximum shear is attained, while the post-peak displacement is ignored in terms of defining ductility. Finally, the third trend, Pattern C, is depicted in the right graph in Figure 10. In essence, Pattern C displays no measurable useful shear connection ductility. This pattern is characteristic for shear connections with very slender ribs and such connections are not likely to be experienced in practice within the scope of the AISC 360 Chapter I provisions. Pattern A is common and can be seen in both the shear connections with strong stud positions and those with studs in a weak position. Pattern B occurs mainly in certain connections featuring studs in strong position.

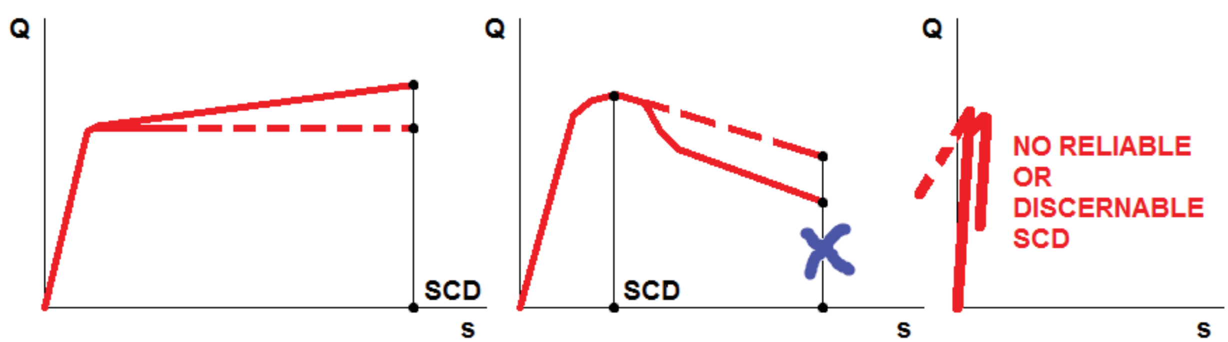

Figure 10 Typical Patterns of Shear Connection Ductility (SCD)

Stud position within the shear connection appears to have the major impact on shear connection ductility and the consistency with which such ductility is achieved. From the survey of the push-out tests with ¾-in. dia. studs reported by Roddenberry et al. (2002), and by defining the shear connection ductility as the maximum slip at which at least 95% of the maximum recorded load can be maintained, the following mean values of shear connection ductility and the corresponding coefficients of variation are obtained for the stud configurations shown:

- solid slabs: slip = 0.36 in., C.o.V. = 0.26;
- slabs on formed deck with studs in strong position: slip = 0.35 in., C.o.V. = 0.34;
- slabs on formed deck with studs in weak position: slip = 0.80 in., C.o.V. = 0.16;
- slabs on formed deck with two studs in strong position: slip = 0.30 in., C.o.V. = 0.25;
- slabs with slender 6-in. deep deck ribs: slip = -0.02 in., C.o.V. = -1.44.

As can be seen from the above information, although the strong stud position is desirable from the standpoint of the ability to achieve the maximum strength of shear connection, the weak stud position is associated with most ductile and statistically consistent response. However, weak stud position is not commonly specified in practice, and the response characteristic to the strong stud position bears most relevance. It can also be observed that a similar average value of shear connection ductility is achieved in solid slabs and the ribbed slabs with strong-position studs, albeit the solid slab slip capacities are considerably more statistically stable. Finally, slabs with slender ribs, as described above and as evident from the presented data, yield statistically meaningless indices. Further refinement in the ability to predict the slip capacity could be possible by considering the parameters such as f'_c, stud height, rib height, etc. However, this is beyond the scope of this study.

In terms of shear connection ductility (slip capacity), this study utilized Eq. 11 based on the work by Oehlers and Coughlan (1986). Equation 11 nominally yields a ductility of 0.25 in. with f'_c of 4 ksi, solid slab configuration and stud diameter of 0.75 in. It further modifies this ductility upward with a decreasing f'_c and increasing stud diameter. Obviously, the nominal slip value of 0.25 in. is considerably lower than the mean slip value of 0.35 in., obtained from the examination of the above referenced test data. However, no extensive database of full-scale and push-out tests exists on the basis of which the overall system reliability it is assessed. It was therefore deemed prudent to adopt a lower nominal value of the calculated slip capacity. As a result, coupled with a strength reduction factor of 0.90 used to calculate $\phi M_{n,sc}$, this would yield a member reliability commensurate to that implied for the moment strength calculated based on rigid plastic analysis in members where the ductility of the shear connection does not govern the design. The slip capacity of 0.25 in. is achieved in approximately 85% of strong-stud configurations presented by Roddenberry et al. (2002).

The envelope capturing the parameters listed at the outset of this section contains 148 beam and 15 girder cases. The summary of these analyses is presented in Appendix A for the beams and Appendix B for the girders. Girders typically do not exhibit a pronounced ductility demand in shear connection, and the 15 cases in the Appendix B are presented merely for illustrative purposes. Specifically, Eq. 4 can be viewed as having two terms on the right hand side, where the first term represents the slip of the concrete slab relative to the supporting steel member in a hypothetical scenario in which the two are completely unconnected and free to slip under member flexure as two independent members with the identical bending curvature. The second term, in turn, is the restraint (or "negative slip") produced by the presence of shear connection of certain strength. It is then evident from examination of the relative relationships between the components within Equations 5 through 9 that the uniformly loaded members (beams) are considerably more sensitive to interface ductility than point-loaded members (girders). The difference is most drastic in comparison between beams and single-point-load girders, and less significant in girders with multiple point loads, which bear closer resemblance to uniform load. As can be seen from Appendix B for the illustrated various cases of 1/3-point loaded girders, $\phi M_{n,sc}$, shown as ϕM_{fr} in the column A26, in all cases considerably exceeds both the factored M_u (column A16) and $\phi M_{n,RPA}$ (shown as ϕM_n in column A17), therefore rendering practically irrelevant the moment envelope curve limited by the stud slip capacity. The evaluation in this study, therefore, focused on beams.

Finally, it should be noted that the strength of the mixed analysis approach lays in its computational simplicity and the intuitive and easily understood mechanistic infrastructure capturing the chief parameters with the impact on shear connection ductility. As such, it is fairly conducive to a routine use. However, its benefits also represent its limitation. Specifically, the approach neglects the effect of slab reinforcement, steel deck, concrete slab cracking, incidental attachments along the interface (e.g., friction and deck attachment welds) and flexural restraints provided by the beam end connections. Furthermore, experimental data is unavailable whereby a deliberate consideration of the approach can be performed both to assess its accuracy across a wide range of data and to confirm the appropriate indices for the reliability based design. Therefore, the approach should be treated as a rational engineering methodology aimed at capturing significant disconnects between the required and available shear connection ductility at the slab-beam interface within composite members. Testing or more advanced numerical methods, as outlined in Section 3, are recommended for performance-based design, or where greater degree of accuracy is needed.

3 Summary of Findings and Recommendations

It is hereby emphasized that the composite members studied are configured as to fully meet the criteria outlined in Sec. 2. As such, shear connection in some members is governed by strength requirements based on rigid plastic analysis, while in others, the shear connection is dictated by the serviceability or detailing consideration. In certain cases, as noted in Appendix A, the beam sizes were increased to satisfy the fabrication requirements for camber, or for vibration performance. Other than considerations such as these, the beams were in all cases optimized for the least-weight solution. Based upon the assessment of a comprehensive envelope of these beam cases, the following observations can be made:

- Beams under 30 ft in span, satisfying the design considerations other than strength, designed using rigid plastic analysis and optimized for the lowest weight of the steel beam, possess adequate shear connection strength to achieve the adequate capacity for the load supported. In these beams, either the rigid plastic analysis moment envelope (RPAME), as illustrated in Figure 7, is not intersected by the moment envelope based on the slip capacity of shear connection (SCME), also illustrated in Figure 7, or the beam configuration is such that even though the SCME might govern over a shear connection degree range, the resulting beam still possesses a safe capacity along the SCME; in other words, moment capacity represented by Point C, as illustrated in Figure 7, is sufficient from the standpoint of resisting the required moment. Examples of this are the cases 1, 2, 23 and 24 in Table 1 of Appendix A.

- 30-ft long beams represent a transitional threshold, whereby some are affected by the excessive ductility demand and the others are not. The impact in those that are could be considered marginal. Furthermore, the practical consequence of the contribution of incidental member continuity through slab reinforcement and end connection fixity, as well as the contribution of interfacial friction and somewhat conservative consideration of the available shear connection ductility, as outlined in Section 2, lead to the conclusion that practically occurring 30-ft long composite beams are not likely to experience large disconnects between the available and required shear connection ductility.
- In general, it is observed that the difference in required and available shear connection ductility increases with the increasing beam span length. It would follow from this trend that the SCME controls the available flexural strength in all very long beams. However, this is not always the case, and cannot be stated as a universal rule. Specifically, shear connection in some longer beams, such is the Case 9 from Table 1 of Appendix A is experiencing no disconnect in the provided and available shear connection ductility based on rigid plastic analysis. As can be seen, based on its specific configuration of geometry and loads, the beam had to be design as 62% composite using rigid plastic analysis, which is sufficient to limit the shear connection ductility demand to the available value, and therefore also resulting in a configuration whereby SCME does not intersect the RPAME (i.e., the point F in Figure 7 does not exist since SCME is located above the RPAME). As such, the moment strength based on the available slip capacity did not control, and was not calculated.
- It is not a foregone conclusion that beams whose design configuration is governed by design considerations other that flexural strength based on rigid plastic analysis are adequate from the standpoint of required and available shear connection ductility. As an example, Cases 21 and 22 in Table 1 of Appendix A both reflect the scenarios in which the beam size is dictated by vibration performance, dictating the increase in the beam size from the original W30x90 to W30x108 and from the original W30x99 to W30x118, respectively. The resulting shear connection was in turn governed by the minimum stud spacing requirements of ANSI/AISC 360-10. However, even though the selection of the size and the shear connection was dictated by the vibration performance, which yielded a more than adequate flexural strength based on rigid plastic analysis (in Case 21: 1215 kip-ft required vs. 1648 kip-ft available; and in Case 22: 1402 kip-ft required vs. 1970 kip-ft available), a large disconnect between the required and the available shear connection ductility rendered both beams flexural inadequate, whereas the computed controlling strength based on SCME were far below the required values (910 kip-ft in Case 21 and 1060 kip-ft in Case 22).
- Disconnect between the required and the provided shear connection ductility was more prevalent among composite beams with normalweight concrete (NWC) slabs than those with lightweight concrete (LWC). The concrete in NWC slabs weighs more, and there needs to be more of it due to fire rating considerations. This necessitates the need for a larger pre-composite strength, resulting in fewer studs for the design under total load. As a result, such members typically feature a lesser degree of composite action than their LWC counterparts. This can be seen from the comparative cases in Tables 1, 2 and 3 of Appendix A.
- The effect of live load magnitude is investigated in Table 3 of Appendix A. In theory, it can be shown that a larger post-composite load will typically correlate with the higher number of studs and fewer instances in which the SCME would govern. However, such a pattern could not be established based on the practically occurring cases presented here given the influence of other design considerations.
- By and large, a higher f'_c was observed as hurting the ductility performance, although this effect isn't overly pronounced. This is evident from the survey of the results presented in Table 2 of Appendix A.
- The effect of deck profile, such as the commercially available Vulcraft 2VL and 3VL, on the performance related to shear connection ductility, does appear to be any detectable in the practically occurring composite beams, as evidenced by the Appendix A data.

The following summarizes a few possible approaches in which the sufficient shear connection ductility can be assured in typical composite members encountered in practice:

(1) Providing minimum shear connection strength in members longer than 30-ft equivalent to one ¾”-dia. stud per ft in the following configurations:

a. Studs are welded through a 2-in. or a 3-in. deep composite deck oriented perpendicular to the member,
b. Studs are installed in the strong position,
c. One or two studs are placed in each rib.

if the following applies:

d. Beams are simply supported,
e. The total slab thickness does not exceed 7 ½ in.,
f. Total factored composite load does not exceed 1.8 kips/ft,
g. The minimum applicable deflection criteria are L/240 under total load, L/360 under live load and L/200 under pre-composite dead load,
h. Member is designed considering all applicable provisions of AISC 360, Chapter I.

The above criteria stems from a fortuitous observation of application of the mixed analysis approach by Oehelrs and Sved (1995) to a matrix capturing wide variety of design configurations encountered in the US design practice, within the confines identified above. As can be seen from the Appendix A data, provided all other design considerations, including serviceability and pre-composite strength are addressed, the resulting configuration will at the minimum provide the flexural capacity equal to the required strength, whether the member is governed by the fully plastic section strength or by the elastic or partially yielded section controlled by the limited ductility of the shear connection. In this scenario, the stud spacing is not in itself critical. However, given the fact that the member length is one of the most critical aspects controlling the shear connection ductility demand, the spacing subject to the above condition provides a simple and convenient length based strength function to help control the ductility demand in longer members, while avoiding unreasonable degrees of shear connection in shorter members where the ductility demand is limited.

(2) Providing a minimum degree of shear connection of 50% in members longer than 30 ft.
This approach results from the same basis as (1), except it offers further simplicity by eliminating the length based requirement embodied in stud spacing and consequently imposing the most critical degree of shear connection observed anywhere in the matrix of the considered cases. The same degree of shear connection was previously recommended by the commentary. Furthermore, this is consistent with the recent findings of Selden et al. (2014).

(3) Direct application of indirect approaches, such as the mixed analysis approach by Oehlers and Sved, criteria provided by ENV 1994-1-1, or the parametric approach by Johnson and Molenstra.

(4) Direct non-linear modeling of the member capturing all sources of deformation. Such a modeling should be performed under factored loads and strength and stiffness properties of the member. It should meet the pertinent requirements of Appendix 1 of the Specification. Furthermore, the analytical model must be validated using experimental data with respect to the load-deformation properties of both the member global behavior and the behavior of the shear connection. Such a validation should utilize unfactored strength and stiffness properties matching the constitutive models reflected in the actual experimental data. Experimental data providing insight into the load-deformation response of shear connection and the composite member as a whole is provided by Roddenberry & Easterling (2002) and other similar references containing reliable load-displacement relationships from applicable push-out tests.

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Appendix A – Beam Data (Tables 1, 2 and 3)

The following it the explanation of the individual cell data in Appendix A tables.

A1	composite beam case number
A2	beam configuration (span, deck type, concrete type, live load, superimposed dead load)
A3	beam size, camber, number of studs
A4	stud diameter
A5	deck rib height
A6	concrete unit weight
A7	total slab thickness
A8	concrete compressive strength
A9	bare steel beam moment of inertia
A10	depth of the bare steel beam
A11	effective slab width (refer to ANSI/AISC 360-10)
A12	strength of shear connection per shear span
A13	cross-sectional area of the bare steel beam
A14	calculated degree of shear connection (refer to the report text for definition)
A15	span length (see also A2)
A16	required moment strength using LRFD load combinations
A17	factored available strength using rigid plastic analysis and the strength reduction factor of 0.9
A18	concrete modulus of elasticity (refer to ANSI/AISC 360-10)
A19,20	refer to Section 2.1 of the report
A21	available slip capacity
A25	strength calculated based on SCME, not calculated when SCME does not govern (i.e., SCME located above RPAME)
A25X	factored plastic moment strength of the bare steel beam per Chapter F of ANSI/AISC 360-10
A26	required shear connection strength when SCME governs to reach a safe capacity equal to the required moment strength (A16), point C in Figure 7, not calculated when SCME does not govern
A27	degree of composite action corresponding to A26 or A14, whichever governs
A27X	average stud spacing to achieve A27 based on the strength of a shear connection with a single strong-position ¾-in. diameter stud
A28-33	refer to Section 2.1
A34	strength of shear connection required to achieve the moment strength corresponding to Point F in Figure 7 by performing rigid plastic analysis; effectively, this is determining what minimum degree of shear connection would result in a sufficient capacity if the user were to use rigid plastic analysis, even though the SCME applies; this is not calculated when SCME does not govern
A35	factored moment strength computed using RPA corresponding to the shear connection strength in A34, not computed when SCME does not govern
A36	computed available moment strength based on SCME and corresponding to the shear connection strength in A34, this is the moment strength corresponding to Point F in Figure 7, not computed when SCME does not govern
A37	degree of shear connection corresponding to A34 and Point F in Figure 7, not computed when SCME does not govern

TABLE 1

No.	Scenario	Beam Size	d_s (in.)	h_r (in.)	w_c (pcf)	t_s (in.)	f'_c (ksi)	I_x ($in.^4$)	d (in.)	b_{eff} (in.)	ΣQ_n (kip)	A_s ($in.^2$)	%C	L (ft)	M_u (kip-ft)	ΦM_n (kip-ft)	E_c (ksi)	h_c (in.)	h_s (in.)	S_u (in.)
1	20ft-3VL-LWC-100LL-15SD	W12X16 (10)	0.75	3	110	6.25	3	103	12	60	85.50	4.71	36.3	20	117.4	139.6	1998	4.63	6	0.261
2	25ft-3VL-LWC-100LL-15SD	W14X22(18)	0.75	3	110	6.25	3	199	13.7	75	153.9	6.49	47.4	25	174.1	232.1	1998	4.63	6.85	0.261
3	30ft-3VL-LWC-100LL-15SD	W16x26 (10) c=3/4"	0.75	3	110	6.25	3	301	15.7	90	85.5	7.68	22.3	30	240.7	244.2	1998	4.63	7.85	0.261
4	35ft-3VL-LWC-100LL-15SD	W16x26 (26) c=1.25"	0.75	3	110	6.25	3	301	15.7	105	222.3	7.68	57.9	35	316.5	321.7	1998	4.63	7.85	0.261
5	40ft-3VL-LWC-100LL-15SD	W18X35 (20) c=1.50"	0.75	3	110	6.25	3	510	17.7	120	171.03	10.3	33.2	40	403.8	403.3	1998	4.63	8.85	0.261
6	45ft-3VL-LWC-100LL-15SD	W18x40 (36) c=2"	0.75	3	110	6.25	3	612	17.9	120	307.85	11.8	52.2	45	500.3	523.9	1998	4.63	8.95	0.261
7	50ft-3VL-LWC-100LL-15SD	W21x44 (40) c=2.25"	0.75	3	110	6.25	3	843	20.7	120	342.06	13.0	52.6	50	606.3	645.3	1998	4.63	10.35	0.261
8	55ft-3VL-LWC-100LL-15SD	W24x55 (32) c=2.0"	0.75	3	110	6.25	3	1350	23.6	120	273.65	16.2	33.8	55	725.2	794.3	1998	4.63	11.8	0.261
9	60ft-3VL-LWC-100LL-15SD	W24x62 (66) c= 2.5"	0.75	3	110	6.25	3	1550	23.7	120	564.39	18.2	62.0	60	852.9	1028.1	1998	4.63	11.85	0.261
10	65ft-3VL-LWC-100LL-15SD	W30x90 (22) c= 1.50"	0.75	3	110	6.25	3	3610	29.5	120	188.13	26.4	18.9	65	1010.1	1441.2	1998	4.63	14.75	0.261
11	70ft-3VL-LWC-100LL-15SD	W33x118(24) c= 1.25"	0.75	3	110	6.25	3	5900	32.9	120	205.23	32.9	20.6	70	1170.7	1874.9	1998	4.63	16.45	0.261
12	20ft-3VL-NWC-100LL-15SD	W12X19 (14)	0.75	3	150	7.5	3	130	12	60	150.8	5.57	54.1	20	136.4	205.2	3182	5.25	6	0.261
13	25ft-3VL-NWC-100LL-15SD	W16x26 (10)	0.75	3	150	7.5	3	301	15.7	75	107.69	7.68	28.0	25	203.9	270.2	3182	5.25	7.85	0.261
14	30ft-3VL-NWC-100LL-15SD	W16X26 (12) C=1.25"	0.75	3	150	7.5	3	301	15.7	90	129.2	7.68	33.7	30	283.1	286.9	3182	5.25	7.85	0.261
15	35ft-3VL-NWC-100LL-15SD	W18x35 (12) c=1.25"	0.75	3	150	7.5	3	510	17.7	105	129.2	10.3	25.1	35	375.9	385.0	3182	5.25	8.85	0.261
16	40ft-3VL-NWC-100LL-15SD	W21x44 (14) c=1.5"	0.75	3	150	7.5	3	843	20.7	120	150.76	13.0	23.2	40	481.5	533.8	3182	5.25	10.35	0.261
17	45ft-3VL-NWC-100LL-15SD	W21x50 (16) c=2"	0.75	3	150	7.5	3	984	20.8	120	172.3	14.7	23.4	45	598.8	610.7	3182	5.25	10.4	0.261
18	50ft-3VL-NWC-100LL-15SD	W24x55 (18) c=2.25"	0.75	3	150	7.5	3	1350	23.6	120	193.8	16.2	23.9	50	728.4	744.4	3182	5.25	11.8	0.261
19	55ft-3VL-NWC-100LL-15SD	W24X68 (20) c=2.50"	0.75	3	150	7.5	3	1830	23.7	120	215.37	20.1	21.4	55	874	928.36	3182	5.25	11.85	0.261
20	60ft-3VL-NWC-100LL-15SD	W27x84 (20) c=2.25"	0.75	3	150	7.5	3	2850	26.7	120	215.4	24.7	17.4	60	1034.9	1212.4	3182	5.25	13.35	0.261
21	65ft-3VL-NWC-100LL-15SD	W30x108 (22) c=2.0"	0.75	3	150	7.5	3	4470	29.8	120	236.91	31.7	17.2	65	1215.1	1647.98	3182	5.25	14.9	0.261
22	70ft-3VL-NWC-100LL-15SD	W33x118 (24) c=2.0"	0.75	3	150	7.5	3	5900	32.9	120	258.45	34.7	18.8	70	1401.9	1969.9	3182	5.25	16.45	0.261
23	20ft-2VL-LWC-100LL-15SD	W12X19 (8)	0.75	2	110	5.25	3	130	12	60	68.41	5.57	24.6	20	114.7	142.47	1998	3.63	6	0.261
24	25ft-2VL-LWC-100LL-15SD	W14x22 (18)	0.75	2	110	5.25	3	199	13.7	75	153.9	6.49	47.4	25	169.6	220.6	1998	3.63	6.85	0.261
25	30ft-2VL-LWC-100LL-15SD	W16x31 (16)	0.75	2	110	5.25	3	375	15.9	90	136.8	9.1	30.0	30	234.9	309.95	1998	3.63	7.95	0.261
26	35ft-2VL-LWC-100LL-15SD	W18x35 (12) c=0.75"	0.75	2	110	5.25	3	510	17.7	105	102.6	10.3	19.9	35	309.4	343.6	1998	3.63	8.85	0.261
27	40ft-2VL-LWC-100LL-15SD	W18x35 (22) c=1.25"	0.75	2	110	5.25	3	510	17.7	120	188.1	10.3	36.5	40	392.3	400.1	1998	3.63	8.85	0.261
28	45ft-2VL-LWC-100LL-15SD	W18x40 (48) c=1.75"	0.75	2	110	5.25	3	612	17.9	120	410.5	11.8	69.6	45	485.8	535.1	1998	3.63	8.95	0.261
29	50ft-2VL-LWC-100LL-15SD	W21x44 (50) c=2"	0.75	2	110	5.25	3	843	20.7	120	427.6	13.0	65.8	50	588.5	647.76	1998	3.63	10.35	0.261
30	55ft-2VL-LWC-100LL-15SD	W24x55 (40) c=1.75"	0.75	2	110	5.25	3	1350	23.6	120	342.1	16.2	42.2	55	703.7	816.1	1998	3.63	11.8	0.261
31	60ft-2VL-LWC-100LL-15SD	W24x55 (84) c=2.75"	0.75	2	110	5.25	3	1350	23.6	120	718.3	16.2	88.7	60	823.6	936.02	1998	3.63	11.8	0.261
32	65ft-2VL-LWC-100LL-15SD	W30x90 (22) c=1.50"	0.75	2	110	5.25	3	3610	29.5	120	188.13	26.4	18.9	65	974.2	1312.08	1998	3.63	14.75	0.261
33	70ft-2VL-LWC-100LL-15SD	W33x118(24) c= 1.25"	0.75	2	110	5.25	3	5900	32.9	120	205.23	34.7	20.6	70	1135.7	1859.54	1998	3.63	16.45	0.261
34	20 ft-2VL-NWC-100LL-15SD	W12x16 (14)	0.75	2	150	4.5	3	103	12	60	119.7	4.7	50.8	20	121.4	159.5	3182	3.25	6	0.261
35	25 ft-2VL-NWC-100LL-15SD	W16X26 (10)	0.75	2	150	4.5	3	301	15.7	75	85.51	7.7	22.3	25	180.7	245.51	3182	3.25	7.85	0.261
36	30 ft-2VL-NWC-100LL-15SD	W16x26 (12)	0.75	2	150	4.5	3	301	15.7	90	102.6	7.68	26.7	30	249.7	258.8	3182	3.25	7.85	0.261
37	35 ft-2VL-NWC-100LL-15SD	W16x31 (18) c=1.25"	0.75	2	150	4.5	3	375	15.9	105	153.9	9.13	33.7	35	329.7	334.3	3182	3.25	7.95	0.261
38	40 ft-2VL-NWC-100LL-15SD	W18x35 (24) c=1.5"	0.75	2	150	4.5	3	510	17.7	120	205.2	10.3	39.9	40	419.8	428.2	3182	3.25	8.85	0.261
39	45 ft-2VL-NWC-100LL-15SD	W21x44 (18) c=1.5"	0.75	2	150	4.5	3	843	20.7	120	153.9	13	23.7	45	521.9	525.3	3182	3.25	10.35	0.261
40	50 ft-2VL-NWC-100LL-15SD	W21x48 (30) c=2.25"	0.75	2	150	4.5	3	959	20.6	120	256.5	14.1	36.4	50	632.9	644.5	3182	3.25	10.3	0.261
41	55 ft-2VL-NWC-100LL-15SD	W24x55 (32) c=2.25"	0.75	2	150	4.5	3	1350	23.6	120	273.7	16.2	33.8	55	755.7	799.4	3182	3.25	11.8	0.261
42	60 ft-2VL-NWC-100LL-15SD	W24x68 (36) c=2.5"	0.75	2	150	4.5	3	1830	23.7	120	307.9	20.1	30.6	60	892.6	989.8	3182	3.25	11.85	0.261
43	65 ft-2VL-NWC-100LL-15SD	W30x90 (22) c=1.75"	0.75	2	150	4.5	3	3610	29.5	120	188.13	26.4	14.3	65	1046.8	1329.72	3182	3.25	14.75	0.261
44	70 ft-2VL-NWC-100LL-15SD	W33x118 (24) c=1.5"	0.75	2	150	4.5	3	5900	32.9	120	205.23	34.7	14.9	70	1220	1878.78	3182	3.25	16.45	0.261
A1	A2	A3 See note.	A4	A5	A6	A7	A8	A9	A10	A11	A12 See note.	A13	A14 See note.	A15	A16	A17 See note.	A18	A19	A20	A21

Manual Input from 3-6

Points A through D in Figure 7 (columns ΦM_{fr} through $\%C_{req.}$); (Point F) (columns ΣQ_n (kip), $\Phi M_n = \Phi M_{fr}$ through $\%C$, $\Phi M_n = \Phi M_r$)

No.	ΦM_{fr} (kip-ft)	ΦM_p (kip-ft)	$\Sigma Q_{n,req.}$ (kip)	$\%C_{req.}$	Stud spacing (in)	EA_s (kips)	EA_c (kips)	EI_s ($k/in.^2$)	EI_c ($k/in.^2$)	K_1 (1/kips)	K_2 (1/kips)	ΣQ_n (kip), $\Phi M_n = \Phi M_{fr}$	ΦM_n (kip-ft)	ΦM_{fr} (kip-ft)	%C, $\Phi M_n = \Phi M_r$
1	N/A	75.4	N/A	36.3	24.0	136590	389659	2987000	342981	3.19E-06	4.38E-05			N/A	
2	N/A	125	N/A	47.4	16.7	188210	487073	5771000	428726	1.85E-06	2.86E-05			N/A	
3	202.94	166	124.82	32.6	24.7	222720	584488	8729000	514471	1.35E-06	2.30E-05	188.13	305.96	301.5	48.99
4	316.24	166	222.57	58.0	16.1	222720	681903	8729000	600216	1.34E-06	2.26E-05	239.44	328.91	332.6	62.35
5	321.29	249	249.08	48.4	16.5	298700	779317	14790000	685961	8.71E-07	1.64E-05	324.95	479.02	484.0	63.1
6	481.61	294	325.07	55.1	14.2	342200	779317	17748000	685961	7.36E-07	1.42E-05	376.26	552.29	555.8	63.8
7	579.47	358	364.17	56.0	14.1	377000	779317	24447000	685961	5.96E-07	1.29E-05	427.57	679.83	683.3	65.78
8	595.96	503	366.67	45.3	15.4	469800	779317	39150000	685961	4.12E-07	1.02E-05	513.08	920.51	928.6	63.34
9	N/A	574	N/A	62.0	10.9	527800	779317	44950000	685961	3.61E-07	9.13E-06			N/A	
10	763.47	1060	319.18	32.1	20.9	765600	779317	104690000	685961	1.84E-07	6.15E-06	701.22	1715.32	1729.1	70.51
11	1032.43	1560	266.56	26.8	26.9	954100	779317	171100000	685961	1.23E-07	4.92E-06	820.94	2414.95	2420.5	82.55
12	N/A	92.6	N/A	54.1	17.1	161530	859135	3770000	1449790	2.16E-06	3.16E-05			N/A	
13	263.27	166	47.25	12.3	68.3	222720	1073918	8729000	1812237	1.24E-06	2.17E-05	129.22	286.33	284.4	33.65
14	262.81	166	149.83	39.1	25.8	222720	1288702	8729000	2174685	1.20E-06	2.10E-05	193.8	326.59	326.3	50.48
15	310.11	249	190.66	37.0	23.7	298700	1503486	14790000	2537132	8.14E-07	1.55E-05	301.52	495.93	494.6	58.55
16	394.81	358	223.22	34.3	23.1	377000	1718269	24447000	2899580	5.70E-07	1.21E-05	409.2	711.0	704.0	63.0
17	427.08	413	314.09	42.7	18.5	426300	1718269	28536000	2899580	4.98E-07	1.07E-05	488.89	815.64	810.5	66.51
18	500.09	503	364.81	45.0	17.7	469800	1718269	39150000	2899580	4.05E-07	9.62E-06	568.58	994.02	1000.5	70.19
19	589.44	664	420.84	41.9	16.9	582900	1718269	53070000	2899580	3.06E-07	7.52E-06	656.88	1204.86	1200.9	65.36
20	710.68	915	423.50	34.2	18.3	716300	1718269	82650000	2899580	2.17E-07	6.02E-06	781.8	1598.7	1593.1	63.05
21	909.98	1300	411.15	29.8	20.4	919300	1718269	129630000	2899580	1.52E-07	4.73E-06	960.55	2184.83	2177.2	69.76
22	1059.64	1560	435.67	31.6	20.7	1006300	1718269	171100000	2899580	1.25E-07	4.28E-06	1040.24	2577.7	2569.5	75.54
23	N/A	92.6	N/A	24.6	30.0	161530	389659	3770000	342981	2.34E-06	3.13E-05			N/A	
24	N/A	125	N/A	47.4	16.7	188210	487073	5771000	428726	1.69E-06	2.51E-05			N/A	
25	291.11	203	77.94	17.1	39.5	264770	584488	10875000	514471	1.02E-06	1.73E-05	171.03	327.74	323.8	37.46
26	278.74	249	132.20	25.7	27.2	298700	681903	14790000	600216	8.11E-07	1.49E-05	239.44	423.26	420.5	46.49
27	344.53	249	234.71	45.5	17.5	298700	779317	14790000	685961	8.06E-07	1.47E-05	273.65	436.86	432.2	53.13
28	N/A	294	N/A	69.6	11.2	342200	779317	17748000	685961	6.82E-07	1.28E-05			N/A	
29	N/A	358	N/A	65.8	12.0	377000	779317	24447000	685961	5.56E-07	1.17E-05			N/A	
30	696.13	503	347.65	42.9	16.2	469800	779317	39150000	685961	3.87E-07	9.38E-06	461.78	866.23	859.3	57.0
31	N/A	503	N/A	88.7	8.6	469800	779317	39150000	685961	3.87E-07	9.38E-06			N/A	
32	783.28	1060	290.29	29.2	23.0	765600	779317	104690000	685961	1.74E-07	5.79E-06	649.91	1648.55	1646.3	65.4
33	1054.82	1560	241.58	24.3	29.7	1006300	779317	171100000	685961	1.17E-07	4.62E-06	786.73	2341.94	2348.8	79.11
34	N/A	75.4	N/A	50.8	17.1	136590	477297	2987000	248592	2.86E-06	3.59E-05			N/A	
35	236.94	166	23.50	6.1	109.2	222720	596621	8729000	310740	1.23E-06	1.98E-05	136.82	281.38	283.5	35.63
36	225.66	166	129.44	33.7	23.8	222720	715946	8729000	372888	1.22E-06	1.94E-05	205.23	317.14	317.6	53.4
37	281.61	203	206.60	45.2	17.4	264770	835270	10875000	435036	9.90E-07	1.61E-05	273.65	392.9	390.9	59.94
38	358.31	249	267.13	51.9	15.4	298700	954594	14790000	497184	7.92E-07	1.40E-05	342.06	492.43	494.2	66.42
39	375.91	358	281.21	43.3	16.4	377000	954594	24447000	497184	5.45E-07	1.11E-05	427.57	687.85	689.7	65.78
40	505.24	398	365.36	51.8	14.0	408900	954594	27811000	497184	4.79E-07	9.98E-06	461.78	740.94	746.0	65.5
41	594.88	503	395.79	48.9	14.3	469800	954594	39150000	497184	3.80E-07	8.89E-06	530.19	936.79	932.7	65.45
42	720.59	664	430.70	42.8	14.3	582900	954594	53070000	497184	2.82E-07	7.02E-06	598.6	1134.36	1127.8	59.56
43	775.93	1060	339.77	25.7	19.6	765600	954594	104690000	497184	1.71E-07	5.43E-06	718.32	1734.56	1723.0	54.42
44	1041.55	1560	289.87	21.0	24.8	1006300	954594	171100000	497184	1.15E-07	4.30E-06	872.24	2448.82	2447.8	63.34
A1	A25	A25X	A26	A27	A27X	A28	A29	A30	A31	A32	A33	A34 See note.	A35	A36	A37

TABLE NOTES:

Deflection limits: L/240 (DL), L/360 (LL), L/200 (DPC)

3VL 6 1/4" (LW, 115 pcf), 7.5" (NW, 145 pcf)

Minimum camber: 3/4", minimum cambered beam sizes: W8x21, W10x26, W12x22, W14x26 or W16x26

Maximum Stud Spacing = 36"

Note: Qmax is taken as ΣQ_n when computing S_{max} if stud fracture moment governs. Else, it is the min. of ΣQ_{est} and ΣQ_n.

COLUMN NOTES:

1. The inability to place 2 studs per rib necesitated W12x16 (10) instead of W12x14(20) was originally required.
2. W12x19 (14) c=3/4" could not be cambered. Therefore, W14x22(18) is used as the minimum size.
3. W14x22 (20) c=1" could not be cambered. Therefore, W16x26 (12) c=3/4" is used instead.
10. W24x76 (60) c= 2.0" was changed to W30x90 (22) c= 1.50" due to vibration performance.
11. W27x84 (46) c= 2.75" was changed to W33x118 (24) c=1.25" due to vibration performance
12. The inability to camber W12x16 (8) c=3/4", caused the use of W12x19 (14)
13. W14x22 (20) c=3/4" could not be cambered. Therefore, W16x26 (10) is used instead.
21. W30x90 (22) c=2.50" was changed to W30x108 (22) c=2.0" due to vibration performance
22. W30x99 (24) c=3.25" was changed to W33x118 (24) c=2.0" due to vibration performance
23. W10x12 (16) c=3/4" could not be cambered. W12x19 (8) is used instead.
24. W12x16 (22) c=3/4" cannot be cambered. Therefore, W14x22 (18) is used instead.
25. W14x22 (24) c=1" cannot be cambered. Therefore, W16x31 (16) is used instead.
26. W16x26 (28) c=1.25" was changed to W18x35 (12) c=3/4" due to vibration performance.
27. W16x31 (52) c=1.75" was changed to W18x35 (22) c=1.25" due to vibration performance.
32. W24x76 (70) c=2.50" was changed to W30x90 (22) c=1.50" due to vibration performance.
33. W27x84 (52) c=2.50" was changed to W33x118(24) c= 1.25" due to vibration performance.
34. W10x15 (12) c=3/4" could not be cambered. Therefore, W12x16 is used.
35. W12x19 (14) c=1" could not be cambered. Therefore, W16x26 (10) is used.
36. W14x22 (22) c=1.25" could not be cambered. Therefore, W16x26(12) was selected.
43. W27x84(22) c=2.25" was changed to W30x90 (22) c=1.75" due to vibration performance.
44. W27x84 (62) c=3.00" was changed to W33x118 (24) c=1.50" due to vibration performance.

A3. Number of Studs is fewest required while still passing the bending /deflection /stud spacing requirement, but ignoring 25% composite requirement.

A12. Determined based on note A3

A14. Determined based on note A3

A17. Determined based on note A3

A22X. These values are obtained by reducing the number of studs further such that phi*Mn from RPA is about equal to Mu.

A25. Value is RED when phi*Mfr < phi*Mp.

A34. This value changes by the no. of studs, increased until Col A35 is approximately equal to the phi*Mn value given by RPA.

TABLE 2

Manual Input from 3-6 (over columns ΦMfr, ΦMp, ΣQn,req.) — (Point F) (over columns ΣQn, ΦMn, ΦMfr, %C)

No.	Scenario	Beam Size	d_s (in.)	h_r (in.)	w_c (pcf)	t_s (in.)	f'_c (ksi)	I_x (in.^{4})	d (in.)	b_{eff} (in.)	ΣQ_n (kip)	A_s (in.^{2})	%C	L (ft)	M_u (kip-ft)	ΦM_n (kip-ft)	E_c (ksi)	h_c (in.)	h_s (in.)	S_u (in.)	ΦM_{fr} (kip-ft)	ΦM_p (kip-ft)	$\Sigma Q_{n,req.}$ (kip)	$\%C_{req.}$	Stud spacing (in)	EA_s (kips)	EA_c (kips)	EI_s (k/in.^{2})	EI_c (k/in.^{2})	K_1 (1/kips)	K_2 (1/kips)	ΣQ_n (kip), $\Phi M_n = \Phi M_{fr}$	ΦM_n (kip-ft)	ΦM_{fr} (kip-ft)	%C, $\Phi M_n = \Phi M_r$	
1	20ft-3VL-LWC-100LL-15SD	W12X16 (10)	0.75	3	110	6.25	3	103	12	60	85.50	4.71	36.3	20	117.4	139.6	1998	4.63	6	0.261	N/A	75.4	N/A	36.3	24.0	136590	389659	2987000	342981	3.19E-06	4.38E-05			N/A		
1A	20ft-3VL-LWC-100LL-15SD	W12X14 (16)	0.75	3	110	6.25	4	88.6	11.9	60	169.8	4.16	81.6	20	117.3	167.0	2307	4.63	5.95	0.245	N/A	65.3	N/A	81.6	12.1	120640	449939	2569400	396040	3.57E-06	4.82E-05			N/A		
2	25ft-3VL-LWC-100LL-15SD	W14X22(18)	0.75	3	110	6.25	3	199	13.7	75	153.9	6.49	47.4	25	174.1	232.1	1998	4.63	6.85	0.261	N/A	125	N/A	47.4	16.7	188210	487073	5771000	428726	1.85E-06	2.86E-05			N/A		
2A	25ft-3VL-LWC-100LL-15SD	W14x22 (14)	0.75	3	110	6.25	4	199	13.7	75	148.6	6.49	45.8	25	174.1	230.9	2307	4.63	6.85	0.245	228.80	125	85.23	26.3	30.1	188210	562424	5771000	495050	1.83E-06	2.81E-05	148.6	230.9	228.8	45.8	
3	30ft-3VL-LWC-100LL-15SD	W16x26 (10) c=3/4"	0.75	3	110	6.25	3	301	15.7	90	85.50	7.68	22.3	30	240.7	244.2	1998	4.63	7.85	0.261	202.94	166	124.82	32.6	24.7	222720	584488	8729000	514471	1.35E-06	2.30E-05	188.1	306.0	301.5	49.0	
3A	30ft-3VL-LWC-100LL-15SD	W16x26 (10) c=3/4"	0.75	3	110	6.25	4	301	15.7	90	106.10	7.68	27.6	30	240.7	259.8	2307	4.63	7.85	0.245	215.73	166	132.31	34.4	23.3	222720	674908	8729000	594060	1.34E-06	2.27E-05	212.2	318.1	316.8	55.3	
4	35ft-3VL-LWC-100LL-15SD	W16x26 (26) c=1.25"	0.75	3	110	6.25	3	301	15.7	105	222.3	7.7	57.9	35	316.5	321.7	1998	4.63	7.85	0.261	316.24	166	222.57	58.0	16.1	222720	681903	8729000	600216	1.34E-06	2.26E-05	239.4	328.9	332.6	62.4	
4A	35ft-3VL-LWC-100LL-15SD	W16x26 (20) c=1.25"	0.75	3	110	6.25	4	301	15.7	105	212.2	7.68	55.3	35	316.5	318.9	2307	4.63	7.85	0.245	300.14	166	229.48	59.8	15.6	222720	787393	8729000	693070	1.32E-06	2.23E-05	254.7	337.5	340.3	66.3	
5	40ft-3VL-LWC-100LL-15SD	W18X35 (20) c=1.50"	0.75	3	110	6.25	3	510	17.7	120	171.03	10.3	33.2	40	403.8	403.3	1998	4.63	8.85	0.261	321.29	249	249.08	48.4	16.5	298700	779317	14790000	685961	8.71E-07	1.64E-05	324.95	479.02	484.0	63.1	
5A	40ft-3VL-LWC-100LL-15SD	W18X35 (16) c=1.50"	0.75	3	110	6.25	4	510	17.7	120	191	10.3	37.1	40	403.8	417.1	2307	4.63	8.85	0.245	333.21	249	258.35	50.2	15.9	298700	899878	14790000	792080	8.65E-07	1.61E-05	339.5	488.5	488.9	65.9	
6	45ft-3VL-LWC-100LL-15SD	W18x40 (36) c=2"	0.75	3	110	6.25	3	612	17.9	120	307.9	11.8	52.2	45	500.3	523.9	1998	4.63	8.95	0.261	481.67	294	325.07	55.1	14.2	342200	779317	17748000	685961	7.36E-07	1.42E-05	376.3	552.3	555.8	63.8	
6A	45ft-3VL-LWC-100LL-15SD	W18x40 (26) c=2"	0.75	3	110	6.25	4	612	17.9	120	275.9	11.8	46.8	45	500.3	512.4	2307	4.63	8.95	0.245	435.84	294	335.95	57.0	13.7	342200	899878	17748000	792080	7.32E-07	1.40E-05	403.2	568.0	572.5	68.3	
7	50ft-3VL-LWC-100LL-15SD	W21x44 (40) c=2.25"	0.75	3	110	6.25	3	843	20.7	120	342.06	13	52.6	50	606.3	645.3	1998	4.63	10.35	0.261	579.47	358	364.17	56.0	14.1	377000	779317	24447000	685961	5.96E-07	1.29E-05	427.6	679.8	683.3	65.8	
7A	50ft-3VL-LWC-100LL-15SD	W21x44 (30) c=2.25"	0.75	3	110	6.25	4	843	20.7	120	318.3	13.0	49.0	50	606.3	637.5	2307	4.63	10.35	0.245	536.82	358	376.24	57.9	13.6	377000	899878	24447000	792080	5.93E-07	1.26E-05	445.7	692.9	689.5	68.6	
8	55ft-3VL-LWC-100LL-15SD	W24x55 (32) c=2.0"	0.75	3	110	6.25	3	1350	23.6	120	273.7	16.2	33.8	55	725.2	794.3	1998	4.63	11.8	0.261	596.03	503	366.67	45.3	15.4	469800	779317	39150000	685961	4.12E-07	1.02E-05	513.1	920.5	928.6	63.3	
8A	55ft-3VL-LWC-100LL-15SD	W24x55 (24) c=2.0"	0.75	3	110	6.25	4	1350	23.6	120	254.7	16.2	31.4	55	725.2	781.3	2307	4.63	11.8	0.245	551.67	503	381.63	47.0	14.8	469800	899878	39150000	792080	4.11E-07	9.99E-06	530.5	935.6	928.8	65.5	
9	60ft-3VL-LWC-100LL-15SD	W24x62 (66) c= 2.5"	0.75	3	110	6.25	3	1550	23.7	120	564.4	18.2	62.0	60	852.9	1028.1	1998	4.63	11.85	0.261	N/A	574	N/A	62.0	10.9	527800	779317	44950000	685961	3.61E-07	9.13E-06			N/A		
9A	60ft-3VL-LWC-100LL-15SD	W24x62 (48) c= 2.5"	0.75	3	110	6.25	4	1550	23.7	120	509.3	18.2	56.0	60	852.9	1015.3	2307	4.63	11.85	0.245	924.03	574	458.36	50.4	13.4	527800	899878	44950000	792080	3.60E-07	8.94E-06	594.2	1049.7	1042.6	65.3	
10	65ft-3VL-LWC-100LL-15SD	W30x90 (22) c= 1.50"	0.75	3	110	6.25	3	3610	29.5	120	188.13	26.4	18.9	65	1010.1	1441.2	1998	4.63	14.75	0.261	763.47	1060	319.18	32.1	20.9	765600	779317	104690000	685961	1.84E-07	6.15E-06	701.2	1715.3	1729.1	70.5	
10A	65ft-3VL-LWC-100LL-15SD	W30x90 (22) c=1.50"	0.75	3	110	6.25	4	3610	29.5	120	233.43	26.4	17.7	65	1004.3	1381.63	2307	4.63	14.75	0.245	812.67	1060	338.14	25.6	19.7	765600	899878	104690000	792080	1.84E-07	5.98E-06	740.7	1745.3	1741.0	56.1	v
11	70ft-3VL-LWC-100LL-15SD	W33x118(24) c= 1.25"	0.75	3	110	6.25	3	5900	32.9	120	205.23	32.9	20.6	70	1170.7	1874.93	1998	4.63	16.45	0.261	1032.43	1560	266.56	26.8	26.9	954100	779317	171100000	685961	1.23E-07	4.92E-06	820.9	2415.0	2420.5	82.6	
11A	70ft-3VL-LWC-100LL-15SD	W30x116 (24) c=1.5"	0.75	3	110	6.25	4	4930	30	120	254.66	34.2	19.2	70	1169.4	1776.39	2307	4.63	15	0.245	985.14	1420	347.85	26.2	20.6	991800	899878	142970000	792080	1.37E-07	4.80E-06	896.7	2247.0	2254.5	67.6	v
12	20ft-3VL-NWC-100LL-15SD	W12X19 (14)	0.75	3	150	7.5	3	130	12	60	150.8	5.57	54.1	20	136.4	205.2	3182	5.25	6	0.261	N/A	92.6	N/A	54.1	17.1	161530	859135	3770000	1449790	2.16E-06	3.16E-05			N/A		
12A	20ft-3VL-NWC-100LL-15SD	W12x19 (12)	0.75	3	150	7.5	4	130	12	60	129.2	5.57	46.4	20	136.4	194.9	3674	5.25	6	0.245	N/A	92.6	N/A	46.4	20.0	161530	992043	3770000	1674073	2.07E-06	3.04E-05			N/A		
13	25ft-3VL-NWC-100LL-15SD	W16x26 (10)	0.75	3	150	7.5	3	301	15.7	75	107.69	7.68	28.0	25	203.9	270.2	3182	5.25	7.85	0.261	263.27	166	47.25	12.3	68.3	222720	1073918	8729000	1812237	1.24E-06	2.17E-05	129.22	286.33	284.4	33.65	
13A	25ft-3VL-NWC-100LL-15SD	W16x26 (10)	0.75	3	150	7.5	4	301	15.7	75	107.69	7.7	28.0	25	203.9	270.75	3674	5.25	7.85	0.245	257.92	166	52.73	13.7	61.2	222720	1240054	8729000	2092591	1.21E-06	2.12E-05	150.8	302.0	300.3	39.3	
14	30ft-3VL-NWC-100LL-15SD	W16X26 (12) C=1.25"	0.75	3	150	7.5	3	301	15.7	90	129.2	7.7	33.7	30	283.1	286.9	3182	5.25	7.85	0.261	262.81	166	149.83	39.1	25.8	222720	1288702	8729000	2174685	1.20E-06	2.10E-05	193.8	326.6	326.3	50.5	
14A	30ft-3VL-NWC-100LL-15SD	W16X26 (12) C=1.25"	0.75	3	150	7.5	4	301	15.7	90	129.2	7.7	33.7	30	283.1	287.6	3674	5.25	7.85	0.245	259.02	166	153.63	40.1	25.2	222720	1488065	8729000	2511110	1.17E-06	2.04E-05	215.4	339.7	344.0	56.1	
15	35ft-3VL-NWC-100LL-15SD	W18x35 (12) c=1.25"	0.75	3	150	7.5	3	510	17.7	105	129.2	10.3	25.1	35	375.9	385	3182	5.25	8.85	0.261	310.11	249	190.66	37.0	23.7	298700	1503486	14790000	2537132	8.14E-07	1.55E-05	301.5	495.9	494.6	58.6	
15A	35ft-3VL-NWC-100LL-15SD	W18x35 (12) c=1.25"	0.75	3	150	7.5	4	510	17.7	105	129.2	10.3	25.1	35	375.9	385.6	3674	5.25	8.85	0.245	303.55	249	196.78	38.2	22.9	298700	1736076	14790000	2929628	7.96E-07	1.51E-05	323.1	510.4	511.1	62.7	
16	40ft-3VL-NWC-100LL-15SD	W21x44 (14) c=1.5"	0.75	3	150	7.5	3	843	20.7	120	150.8	13.0	23.2	40	481.5	533.8	3182	5.25	10.35	0.261	394.86	358	223.22	34.3	23.1	377000	1718269	24447000	2899580	5.70E-07	1.21E-05	409.2	711.0	704.0	63.0	
16A	40ft-3VL-NWC-100LL-15SD	W21x44 (14) c=1.5"	0.75	3	150	7.5	4	843	20.7	120	150.8	13.0	23.2	40	481.5	534.5	3674	5.25	10.35	0.245	385.03	358	231.61	35.6	22.3	377000	1984087	24447000	3348146	5.61E-07	1.19E-05	445.8	734.8	737.2	68.6	
17	45ft-3VL-NWC-100LL-15SD	W21x50 (16) c=2"	0.75	3	150	7.5	3	984	20.8	120	172.3	14.7	23.4	45	598.8	610.7	3182	5.25	10.4	0.261	427.08	413	314.09	42.7	18.5	426300	1718269	28536000	2899580	4.98E-07	1.07E-05	488.9	815.6	810.5	66.5	
17A	45ft-3VL-NWC-100LL-15SD	W21x50 (16) c=2"	0.75	3	150	7.5	4	984	20.8	120	172.3	14.7	23.4	45	598.8	611.6	3674	5.25	10.4	0.245	416.30	413	323.51	43.9	17.9	426300	1984087	28536000	3348146	4.91E-07	1.05E-05	519.0	837.9	834.8	70.6	
18	50ft-3VL-NWC-100LL-15SD	W24x55 (18) c=2.25"	0.75	3	150	7.5	3	1350	23.6	120	193.8	16.2	23.9	50	728.4	744.4	3182	5.25	11.8	0.261	500.09	503	364.81	45.0	17.7	469800	1718269	39150000	2899580	4.05E-07	9.62E-06	568.6	994.0	1000.5	70.2	
18A	50ft-3VL-NWC-100LL-15SD	W24x55 (18) c=2.25"	0.75	3	150	7.5	4	1350	23.6	120	193.8	16.2	23.9	50	728.4	745.5	3674	5.25	11.8	0.245	486.82	503	375.69	46.3	17.2	469800	1984087	39150000	3348146	4.01E-07	9.47E-06	598.7	1018.4	1024.6	73.9	
19	55ft-3VL-NWC-100LL-15SD	W24X68 (20) c=2.50"	0.75	3	150	7.5	3	1830	23.7	120	215.37	20.1	21.4	55	874	928.36	3182	5.25	11.85	0.261	589.44	664	420.84	41.9	16.9	582900	1718269	53070000	2899580	3.06E-07	7.52E-06	656.88	1204.86	1200.9	65.36	
19A	55ft-3VL-NWC-100LL-15SD	W24X68 (20) c=2.50"	0.75	3	150	7.5	4	1830	23.7	120	215.37	20.1	21.4	55	874	929.78	3674	5.25	11.85	0.245	571.94	664	435.24	43.3	16.3	582900	1984087	53070000	3348146	3.03E-07	7.40E-06	702.1	1239.1	1240.6	69.9	
20	60ft-3VL-NWC-100LL-15SD	W27x84 (20) c=2.25"	0.75	3	150	7.5	3	2850	26.7	120	215.4	24.7	17.4	60	1034.9	1212.4	3182	5.25	13.35	0.261	710.68	915	423.50	34.2	18.3	716300	1718269	82650000	2899580	2.17E-07	6.02E-06	781.8	1598.7	1593.1	63.1	
20A	60ft-3VL-NWC-100LL-15SD	W27x84 (20) c=2.25"	0.75	3	150	7.5	4	2850	26.7	120	215.4	24.7	17.4	60	1034.9	1213.8	3674	5.25	13.35	0.245	686.44	915	441.61	35.7	17.5	716300	1984087	82650000	3348146	2.16E-07	5.92E-06	842.1	1644.3	1651.8	67.9	
21	65ft-3VL-NWC-100LL-15SD	W30x108 (22) c=2.0"	0.75	3	150	7.5	3	4470	29.8	120	236.91	31.7	17.2	65	1215.1	1647.98	3182	5.25	14.9	0.261	909.98	1300	411.15	29.8	20.4	919300	1718269	129630000	2899580	1.52E-07	4.73E-06	960.6	2184.8	2177.2	69.8	
21A	65ft-3VL-NWC-100LL-15SD	W30x108 (22) c=2.00"	0.75	3	150	7.5	4	4470	29.8	120	236.9	31.7	15.0	65	1215.1	1649.7	3674	5.25	14.9	0.245	875.74	1300	433.70	27.4	19.3	919300	1984087	129630000	3348146	1.52E-07	4.65E-06	1035.9	2244.8	2253.5	65.4	v
22	70ft-3VL-NWC-100LL-15SD	W33x118 (24) c=2.0"	0.75	3	150	7.5	3	5900	32.9	120	258.45	34.7	18.8	70	1401.9	1969.9	3182	5.25	16.45	0.261	1059.64	1560	435.67	31.6	20.7	1006300	1718269	171100000	2899580	1.25E-07	4.28E-06	1040.2	2577.7	2569.5	75.5	
22A	70ft-3VL-NWC-100LL-15SD	W33x118 (24) c=2.0"	0.75	3	150	7.5	4	5900	32.9	120	258.45	34.7	18.8	70	1401.9	1971.95	3674	5.25	16.45	0.245	1019.04	1560	460.18	33.5	19.6	1006300	1984087	171100000	3348146	1.24E-07	4.20E-06	1115.6	2641.5	2645.9	64.3	v
23	20ft-2VL-LWC-100LL-15SD	W12X19 (8)	0.75	2	110	5.25	3	130	12	60	68.41	5.57	24.6	20	114.7	142.5	1998	3.63	6	0.261	N/A	92.6	N/A	24.6	30.0	161530	389659	3770000	342981	2.34E-06	3.13E-05			N/A		
23A	20ft-2VL-LWC-100LL-15SD	W12X19 (8)	0.75	2	110	5.25	4	130	12	60	84.89	5.57	30.5	20	114.7	152.3	2307	3.63	6	0.245	N/A	92.6	N/A	30.5	24.2	161530	449939	3770000	396040	2.31E-06	3.07E-05			N/A		
24	25ft-2VL-LWC-100LL-15SD	W14x22 (18)	0.75	2	110	5.25	3	199	13.7	75	153.9	6.49	47.4	25	169.6	220.6	1998	3.63	6.85	0.261	N/A	125	N/A	47.4	16.7	188210	487073	5771000	428726	1.69E-06	2.51E-05			N/A		
24A	25ft-2VL-LWC-100LL-15SD	W14x22 (12)	0.75	2	110	5.25	4	199	13.7	75	127.33	6.49	23.2	25	169.6	210.9	2307	3.63	6.85	0.245	N/A	125	N/A	23.2	20.1	188210	562424	5771000	495050	1.67E-06	2.46E-05			N/A		
25	30ft-2VL-LWC-100LL-15SD	W16x31 (16)	0.75	2	110	5.25	3	375	15.9	90	136.80	9.13	30.0	30	234.9	310.0	1998	3.63	7.95	0.261	291.11	203	77.94	17.1	39.5	264770	584488	10875000	514471	1.02E-06	1.73E-05	171.0	327.7	323.8	37.5	
25A	30ft-2VL-LWC-100LL-15SD	W16X31 (12)	0.75	2	110	5.25	4	375	15.9	90	127.33	9.13	27.9	30	234.9	305.1	2307	3.63	7.95	0.245	272.22	203	87.80	19.2	35.1	264770	674908	10875000	594060	1.01E-06	1.69E-05	191.0	338.0	332.3	41.8	
26	35ft-2VL-LWC-100LL-15SD	W18x35 (12) c=0.75"	0.75	2	110	5.25	3	510	17.7	105	102.6	10.3	19.9	35	309.4	343.6	1998	3.63	8.85	0.261	278.74	249	132.20	25.7	27.2	298700	681903	14790000	600216	8.11E-07	1.49E-05	239.4	423.3	420.5	46.5	
26A	35ft-2VL-LWC-100LL-15SD	W18x35 (12) c=0.75"	0.75	2	110	5.25	4	510	17.7	105	127.33	10.3	24.7	35	309.4	362.4	2307	3.63	8.85	0.245	293.59	249	142.76	27.7	25.2	298700	787393	14790000	693070	8.06E-07	1.47E-05	254.7	431.2	424.0	49.5	
27	40ft-2VL-LWC-100LL-15SD	W18x35 (22) c=1.25"	0.75	2	110	5.25	3	510	17.7	120	188.1	10.3	36.5	40	392.3	400.1	1998	3.63	8.85	0.261	344.53	249	234.71	45.5	17.5	298700	779317	14790000	685961	8.06E-07	1.47E-05	273.7	436.9	432.2	53.1	
27A	40ft-2VL-LWC-100LL-15SD	W18X35 (16) c=1.25"	0.75	2	110	5.25	4	510	17.7	120	169.77	10.3	33.0	40	392.3	390.6	2307	3.63	8.85	0.245	316.03	249	244.91	47.5	16.8	298700	899878	14790000	792080	8.01E-07	1.44E-05	297.1	447.8	445.3	57.7	
28	45ft-2VL-LWC-100LL-15SD	W18x40 (48) c=1.75"	0.75	2	110	5.25	3	612	17.9	120	410.5	11.8	69.6	45	485.8	535.1	1998	3.63	8.95	0.261	N/A	294	N/A	69.6	11.2	342200	779317	17748000	685961	6.82E-07	1.28E-05			N/A		
28A	45ft-2VL-LWC-100LL-15SD	W18x40 (36) c=1.75"	0.75	2	110	5.25	4	612	17.9	120	381.98	11.8	64.7	45	485.8	530.4	2307	3.63	8.95	0.245	N/A	294	N/A	64.7	12.1	342200	899878	17748000	792080	6.78E-07	1.26E-05			N/A		
29	50ft-2VL-LWC-100LL-15SD	W21x44 (50) c=2"	0.75	2	110	5.25	3	843	20.7	120	427.6	13	65.8	50	588.5	647.8	1998	3.63	10.35	0.261	N/A	358	N/A	65.8	12.0	377000	779317	24447000	685961	5.56E-07	1.17E-05			N/A		
29A	50ft-2VL-LWC-100LL-15SD	W21x44 (36) c=2"	0.75	2	110	5.25	4	843	20.7	120	381.98	13.0	58.8	50	588.5	637.6	2307	3.63	10.35	0.245	612.55	358	361.39	55.6	14.2	377000	899878	24447000	792080	5.54E-07	1.15E-05	403.2	645.0	637.3	62.0	
30	55ft-2VL-LWC-100LL-15SD	W24x55 (40) c=1.75"	0.75	2	110	5.25	3	1350	23.6	120	342.1	16.2	42.2	55	703.7	816.1	1998	3.63	11.8	0.261	696.13	503	347.65	42.9	16.2	469800	779317	39150000	685961	3.87E-07	9.38E-06	461.8	866.2	859.3	57.0	
30A	55ft-2VL-LWC-100LL-15SD	W24x55 (30) c=2"	0.75	2	110	5.25	4	1350	23.6	120	318.32	16.2	39.3	55	703.7	805.63	2307	3.63	11.8	0.245	643.08	503	363.58	44.9	15.5	469800	899878	39150000	792080	3.86E-07	9.20E-06	509.3	888.8	898.9	62.9	
31	60ft-2VL-LWC-100LL-15SD	W24x55 (84) c=2.75"	0.75	2	110	5.25	3	1350	23.6	120	718.3	16.2	88.7	60	823.6	936.02	1998	3.63	11.8	0.261	N/A	503	N/A	88.7	8.6	469800	779317	39150000	685961	3.87E-07	9.38E-06			N/A		
31A	60ft-2VL-LWC-100LL-15SD	W24x55 (62) c=2.75"	0.75	2	110	5.25	4	1350	23.6	120	652.03	16.2	80.5	60	823.6	933.21	2307	3.63	11.8	0.245	N/A	503	N/A	80.5	9.4	469800	899878	39150000	792080	3.86E-07	9.20E-06			N/A		
32	65ft-2VL-LWC-100LL-15SD	W30x90 (22) c=1.50"	0.75	2	110	5.25	3	3610	29.5	120	188.13	26.4	18.9	65	974.2	1312.08	1998	3.63	14.75	0.261	783.28	1060	290.29	29.2	23.0	765600	779317	104690000	685961	1.74E-07	5.79E-06	649.9	1648.6	1646.3	65.4	
32A	65ft-2VL-LWC-100LL-15SD	W30x90 (22) c=1.50"	0.75	2	110	5.25	4	3610	29.5	120	233.43	26.4	18.9	65	965.5	1364.12	2307	3.63	14.75	0.245	829.92	1060	308.16	25.0	21.6	765600	899878	104690000	792080	1.74E-07	5.62E-06	694.5	1675.7	1666.3	52.6	v
33	70ft-2VL-LWC-100LL-15SD	W33x118(24) c= 1.25"	0.75	2	110	5.25	3	5900	32.9	120	205.23	34.7	20.6	70	1135.7	1859.54	1998	3.63	16.45	0.261	1054.82	1560	241.58	24.3	29.7	1006300	779317	171100000	685961	1.17E-07	4.62E-06	786.7	2341.9	2348.8	79.1	
33A	70ft-2VL-LWC-100LL-15SD	W30x116 (24) c=1.5"	0.75	2	110	5.25	4	4930	30	120	254.66	34.2	19.2	70	1111	1757.3	2307	3.63	15	0.245	1008.61	1420	306.69	23.1	23.4	991800	899878	142970000	792080	1.30E-07	4.53E-06	850.5	2166.3	2181.2	64.1	v
34	20 ft-2VL-NWC-100LL-15SD	W12x16 (14)	0.75	2	150	4.5	3	103	12	60	119.7	4.71	50.8	20	121.4	159.5	3182	3.25	6	0.261	N/A	75.4	N/A	50.8	17.1	136590	477297	2987000	248592	2.86E-06	3.59E-05			N/A		
34A	20 ft-2VL-NWC-100LL-15SD	W12x16 (12)	0.75	2	150	4.5	4	103	12	60	127.33	4.71	54.1	20	121.4	164	3674	3.25	6	0.245	N/A	75.4	N/A	54.1	16.1	136590	551135	2987000	287050	2.83E-06	3.53E-05			N/A		
35	25 ft-2VL-NWC-100LL-15SD	W16X26 (10)	0.75	2	150	4.5	3	301	15.7	75	85.51	7.7	22.3	25	180.7	245.51	3182	3.25	7.85	0.261	236.94	166	23.50	6.1	109.2	222720	596621	8729000	310740	1.23E-06	1.98E-05	136.8	281.4	283.5	35.6	
35A	25 ft-2VL-NWC-100LL-15SD	W16x26 (10)	0.75	2	150	4.5	4	301	15.7	75	106.11	7.7	27.6	25	180.7	261.53	3674	3.25	7.85	0.245	245.94	166	33.41	8.7	76.8	223300	688919	8729000	358812	1.22E-06	1.95E-05	148.6	289.4	284.0	38.7	
36	30 ft-2VL-NWC-100LL-15SD	W16x26 (12)	0.75	2	150	4.5	3	301	15.7	90	102.6	7.7	26.7	30	249.7	258.8	3182	3.25	7.85	0.261	225.66	166	129.44	33.7	23.8	222720	715946	8729000	372888	1.22E-06	1.94E-05	205.2	317.1	317.6	53.4	
36A	30 ft-2VL-NWC-100LL-15SD	W16x26 (10)	0.75	2	150	4.5	4	301	15.7	90	106.11	7.7	27.6	30	249.7	261.81	3674	3.25	7.85	0.245	220.85	166	138.58	36.1	22.2	223300	826703	8729000	430574	1.21E-06	1.91E-05	233.4	331.7	334.0	60.8	
37	35 ft-2VL-NWC-100LL-15SD	W16x31 (18) c=1.25"	0.75	2	150	4.5	3	375	15.9	105	153.9	9.1	33.7	35	329.7	334.3	3182	3.25	7.95	0.261	281.61	203	206.60	45.2	17.4	264770	835270	10875000	435036	9.90E-07	1.61E-05	273.7	392.9	390.9	59.9	
37A	35 ft-2VL-NWC-100LL-15SD	W16x31 (14) c=1.25"	0.75	2	150	4.5	4	375	15.9	105	148.55	9.1	32.5	35	329.7	331.67	3674	3.25	7.95	0.245	268.12	203	216.53	47.4	16.6	263900	964487	10875000	502337	9.84E-07	1.59E-05	297.1	406.1	402.7	65.1	
38	40 ft-2VL-NWC-100LL-15SD	W18x35 (24) c=1.5"	0.75	2	150	4.5	3	510	17.7	120	205.2	10.3	39.9	40	419.8	428.2	3182	3.25	8.85	0.261	358.31	249	267.13	51.9	15.4	298700	954594	14790000	497184	7.92E-07	1.40E-05	342.1	492.4	494.2	66.4	
38A	40 ft-2VL-NWC-100LL-15SD	W18x35 (18) c=1.25"	0.75	2	150	4.5	4	510	17.7	120	190.99	10.3	37.1	40	419.8	420.67	3674	3.25	8.85	0.245	334.13	249	278.01	54.0	14.8	298700	1102270	14790000	574099	7.88E-07	1.38E-05	360.8	504.3	501.3	70.1	
39	45 ft-2VL-NWC-100LL-15SD	W21x44 (18) c=1.5"	0.75	2	150	4.5	3	843	20.7	120	153.9	13.0	23.7	45	521.9	525.3	3182	3.25	10.35	0.261	375.91	358	281.21	43.3	16.4	377000	954594	24447000	497184	5.45E-07	1.11E-05	427.6	687.9	689.7	65.8	
39A	45 ft-2VL-NWC-100LL-15SD	W21x44 (16) c=1.25"	0.75	2	150	4.5	4	843	20.7	120	169.77	13	26.1	45	521.9	540.13	3674	3.25	10.35	0.245	380.57	358	294.47	45.3	15.7	377000	1102270	24447000	574099	5.44E-07	1.10E-05	466.9	710.3	717.3	71.8	
40	50 ft-2VL-NWC-100LL-15SD	W21x48 (30) c=2.25"	0.75	2	150	4.5	3	959	20.6	120	256.5	14.1	36.4	50	632.9	644.5	3182	3.25	10.3	0.261	505.24	398	365.36	51.8	14.0	408900	954594	27811000	497184	4.79E-07	9.98E-06	461.8	740.9	746.0	65.5	
40A	50 ft-2VL-NWC-100LL-15SD	W21x48 (22) c=1.75"	0.75	2	150	4.5	4	959	20.6	120	233.43	14.1	33.1	50	632.9	630.55	3674	3.25	10.3	0.245	462.95	398	380.28	53.9	13.5	408900	1102270	27811000	574099	4.77E-07	9.82E-06	488.1	758.6	757.7	69.2	
41	55 ft-2VL-NWC-100LL-15SD	W24x55 (32) c=2.25"	0.75	2	150	4.5	3	1350	23.6	120	273.7	16.2	33.8	55	755.7	799.4	3182	3.25	11.8	0.261	594.88	503	395.79	48.9	14.3	469800	954594	39150000	497184	3.80E-07	8.89E-06	530.2	936.8	932.7	65.5	
41A	55 ft-2VL-NWC-100LL-15SD	W24x55 (24) c=1.75"	0.75	2	150	4.5	4	1350	23.6	120	254.66	16.2	31.4	55	755.7	786.08	3674	3.25	11.8	0.245	551.22	503	412.28	50.9	13.7	469800	1102270	39150000	574099	3.79E-07	8.74E-06	573.0	963.1	964.2	70.7	
42	60 ft-2VL-NWC-100LL-15SD	W24x68 (36) c=2.5"	0.75	2	150	4.5	3	1830	23.7	120	307.9	20.1	30.6	60	892.6	989.8	3182	3.25	11.85	0.261	720.59	664	430.70	42.8	14.3	582900	954594	53070000	497184	2.82E-07	7.02E-06	598.6	1134.4	1127.8	59.6	
42A	60 ft-2VL-NWC-100LL-15SD	W24x68 (26) c=2.0"	0.75	2	150	4.5	4	1830	23.7	120	275.88	20.1	27.5	60	892.6	967.31	3674	3.25	11.85	0.245	651.41	664	451.48	44.9	13.6	582900	1102270	53070000	574099	2.81E-07	6.87E-06	652.0	1166.9	1168.0	64.9	
43	65 ft-2VL-NWC-100LL-15SD	W30x90 (22) c=1.75"	0.75	2	150	4.5	3	3610	29.5	120	188.13	26.4	14.3	65	1046.8	1329.72	3182	3.25	14.75	0.261	775.93	1060	339.77	25.7	19.6	765600	954594	104690000	497184	1.71E-07	5.43E-06	718.3	1734.6	1723.0	54.4	
43A	65 ft-2VL-NWC-100LL-15SD	W30x90 (22) c=1.75"	0.75	2	150	4.5	4	3610	29.5	120	233.43	26.4	17.7	65	1043.3	1386.01	3674	3.25	14.75	0.245	820.35	1060	361.52	27.4	18.4	765600	1102270	104690000	574099	1.71E-07	5.29E-06	786.8	1777.0	1783.6	59.6	v
44	70 ft-2VL-NWC-100LL-15SD	W33x118 (24) c=1.5"	0.75	2	150	4.5	3	5900	32.9	120	205.23	34.7	14.9	70	1220	1878.78	3182	3.25	16.45	0.261	1041.55	1560	289.87	21.0	24.8	1006300	954594	171100000	497184	1.15E-07	4.30E-06	872.2	2448.8	2447.8	63.3	
44A	70 ft-2VL-NWC-100LL-15SD	W33x118 (24) c=1.5"	0.75	2	150	4.5	4	5900	32.9	120	254.66	34.7	14.7	70	1195.2	1947.55	3674	3.25	16.45	0.245	1092.42	1560	305.05	17.6	23.5	1006300	1102270	171100000	574099	1.15E-07	4.16E-06	942.8	2498.5	2496.3	54.3	v
A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A25	A25X	A26	A27	A27X	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	Note AQ

TABLE NOTES:

Deflection limits: L/240 (DL), L/360 (LL), L/200 (DPC)

3VL 6 1/4" (LW, 115 pcf; NWC, 50 pcf), 3ksi and 4 ksi slab

Minimum camber: 3/4", minimum cambered beam sizes: W8x21, W10x26, W12x22, W14x26 or W16x26

Maximum Stud Spacing = 36"

Note: Qmax is taken as ΣQ_n when computing S_{max} if stud fracture moment governs. Else, it is the min. of ΣQ_{est} and ΣQ_n.

COLUMN NOTES:

1. The inability to place 2 studs per rib necesitated W12x16 (10) instead of W12x14(20) was originally required.
2. W12x19 (14) c=3/4" could not be cambered. Therefore, W14x22(18) is used as the minimum size.

2A. W12x19 (12) c=3/4" could not be cambered. Therefore, W14x22 (18) is used as the minimum size.

3. W14x22 (20) c=1" could not be cambered. Therefore, W16x26 (12) c=3/4" is used instead.

10. W24x76 (60) c= 2.0" was changed to W30x90 (22) c= 1.50" due to vibration performance.

10A. Changed to W30x90 (22) c= 1.50" due to vibration performance.

11. W27x84 (46) c= 2.75" was changed to W33x118 (24) c=1.25" due to vibration performance

11A. Changed to W30x116 (24) c=1.5" due to vibration performance

12. The inability to camber W12x16 (8) c=3/4", caused the use of W12x19 (14)

12A. The inability to camber W12x16 (8) c=3/4", caused the use of W12x19 (14)

13. W14x22 (20) c=3/4" could not be cambered. Therefore, W16x26 (10) is used instead.

13A. W14x22 (10) c=3/4" could not be cambered. Therefore, W16x26 (8) is used instead.

21. W30x90 (22) c=2.50" was changed to W30x108 (22) c=2.0" due to vibration performance

21A. Changed to W30x108 (22) c=2.00" due to vibration performance

22. W30x99 (24) c=3.25" was changed to W33x118 (24) c=2.0" due to vibration performance

22A. Changed to W33x118 (24) c=2.0" due to vibration performance

23. W10x12 (16) c=3/4" could not be cambered. W12x19 (8) is used instead.

23A. W10x12 (16) c=3/4" could not be cambered. W12x19 (8) is used instead.

24. W12x16 (22) c=3/4" cannot be cambered. Therefore, W14x22 (18) is used instead.

24A. W12x16 (22) c=3/4" cannot be cambered. Therefore, W14x22 (12) is used instead.

25. W14x22 (24) c=1" cannot be cambered. Therefore, W16x31 (16) is used instead.

25A. W14x22 (24) c=1" cannot be cambered. Therefore, W16x31 (12) is used instead.

26. W16x26 (28) c=1.25" was changed to W18x35 (12) c=3/4" due to vibration performance.

26A. W16x26 (28) c=1.25" was changed to W18x35 (12) c=3/4" due to vibration performance.

27. W16x31 (52) c=1.75" was changed to W18x35 (22) c=1.25" due to vibration performance.

27A. W16x31 (52) c=1.75" was changed to W18x35 (22) c=1.25" due to vibration performance.

32. W24x76 (70) c=2.50" was changed to W30x90 (22) c=1.50" due to vibration performance.

32A. Changed to W30x90 (22) c=1.50" due to vibration performance.

33. W27x84 (52) c=2.50" was changed to W33x118(24) c= 1.25" due to vibration performance.

33A. Changed to W30x116(24) c= 1.5" due to vibration performance.

34. W10x15 (12) c=3/4" could not be cambered. Therefore, W12x16 is used.

34A. W10x15 (12) c=3/4" could not be cambered. Therefore, W12x16 is used.

35. W12x19 (10) c=1" could not be cambered. Therefore, W16x26 (10) is used.

35A. W12x19 (10) c=1" could not be cambered. Therefore, W16x26 (10) is used.

36. W14x22 (22) c=1.25" could not be cambered. Therefore, W16x26 (12) is used.

36A. W14x22 (22) c=1.25" could not be cambered. Therefore, W16x26 (10) is used

43. W27x84(22) c=2.25" was changed to W30x90 (22) c=1.75" due to vibration performance.

43A. Changed to W30x90 (22) c=1.75" due to vibration performance.

44. W27x84 (62) c=3.00" was changed to W33x118 (24) c=1.50" due to vibration performance.

44A. Changed to W33x118 (24) c=1.50" due to vibration performance.

A3. Number of Studs is fewest required while still passing the bending /deflection /stud spacing requirement, but ignoring the 25% composite limit.

A12. Determined based on note A3

A14. Determined based on note A3

A17. Determined based on note A3

A22X. Obtained by reducing the number of studs further such that phi*Mn from RPA is about equal to Mu.

A25. Value is RED when phi*Mfr < phi*Mp.

A34. This value changes by no. of studs, increased until Col A35 is approximately equal to the phi*Mn value given by RPA.

AQ. V indicates beam size increased due to vibration performance.

TABLE 3

Manual Input from 3-6

Points A through D | (Point F)

No.	Scenario	Beam Size	d_s (in.)	h_r (in.)	w_c (pcf)	t_s (in.)	f'_c (ksi)	I_x (in.^{4})	d (in.)	b_{eff} (in.)	ΣQ_n (kip)	A_s (in.^{2})	%C	L (ft)	M_u (kip-ft)	ΦM_n (kip-ft)	E_c (ksi)	h_c (in.)	h_s (in.)	S_u (in.)	ΦM_{fr} (kip-ft)	ΦM_p (kip-ft)	$\Sigma Q_{n,req.}$ (kip)	$\%C_{req.}$	Stud spacing (in)	EA_s (kips)	EA_c (kips)	EI_s (k/in.^{2})	EI_c (k/in.^{2})	K_1 (1/kips)	K_2 (1/kips)	ΣQ_n (kip), $\Phi M_n = \Phi M_{fr}$	ΦM_n (kip-ft)	ΦM_{fr} (kip-ft)	%C, $\Phi M_n = \Phi M_r$	
1A	20ft-3VL-LWC-100LL-15SD	W12X14 (16)	0.75	3	110	6.25	4	88.6	11.9	60	169.80	4.16	81.6	20	117.3	167.0	2307	4.63	5.95	0.245	N/A	65.3	N/A	81.6	12.1	120640	449939	2569400	396040	3.57E-06	4.82E-05			N/A		
1B	20ft-3VL-LWC-50LL-15SD	W12X14 (8)	0.75	3	110	6.25	4	88.6	11.9	60	84.89	4.16	40.8	20	89.3	128.4	2307	4.63	5.95	0.245	N/A	65.3	N/A	40.8	24.2	120640	449939	2569400	396040	3.57E-06	4.82E-05			N/A		
2A	25ft-3VL-LWC-100LL-15SD	W14x22 (14)	0.75	3	110	6.25	4	199	13.7	75	148.6	6.49	45.8	25	174.1	230.9	2307	4.63	6.85	0.245	228.80	125	85.23	26.3	30.1	188210	562424	5771000	495050	1.83E-06	2.81E-05	148.6	230.9	228.8	45.8	
2B	25ft-3VL-LWC-50LL-15SD	W14x22 (10)	0.75	3	110	6.25	4	199	13.7	75	106.11	6.49	32.7	25	135.3	208.4	2307	4.63	6.85	0.245	192.12	125	40.29	12.4	63.7	188210	562424	5771000	495050	1.83E-06	2.81E-05	148.6	230.9	228.8	45.8	
3A	30ft-3VL-LWC-100LL-15SD	W16x26 (10) c=3/4"	0.75	3	110	6.25	4	301	15.7	90	106.10	7.68	27.6	30	240.7	259.8	2307	4.63	7.85	0.245	215.73	166	132.31	34.4	23.3	222720	674908	8729000	594060	1.34E-06	2.27E-05	212.2	318.1	316.8	55.3	
3B	30ft-3VL-LWC-50LL-15SD	W16X26 (10) c=3/4"	0.75	3	110	6.25	4	301	15.7	90	106.11	7.68	27.6	30	190.1	259.8	2307	4.63	7.85	0.245	215.74	166	79.20	20.6	38.9	222720	674908	8729000	594060	1.34E-06	2.27E-05	212.2	317.0	316.8	55.3	
4A	35ft-3VL-LWC-100LL-15SD	W16x26 (20) c=1.25"	0.75	3	110	6.25	4	301	15.7	105	212.2	7.68	55.3	35	316.5	318.9	2307	4.63	7.85	0.245	300.14	166	229.48	59.8	15.6	222720	787393	8729000	693070	1.32E-06	2.23E-05	254.7	337.5	340.3	66.3	
4B	35ft-3VL-LWC-50LL-15SD	W16X26 (12) C=1.25"	0.75	3	110	6.25	4	301	15.7	105	127.33	7.68	22.2	35	253.1	274.5	2307	4.63	7.85	0.245	219.82	166	162.50	28.3	22.1	222720	787393	8729000	693070	1.32E-06	2.23E-05	254.7	337.5	340.3	66.3	
5A	40ft-3VL-LWC-100LL-15SD	W18X35 (16) c=1.50"	0.75	3	110	6.25	4	510	17.7	120	191	10.3	37.1	40	403.8	417.1	2307	4.63	8.85	0.245	333.21	249	258.35	50.2	15.9	298700	899878	14790000	792080	8.65E-07	1.61E-05	339.5	488.5	488.9	65.9	
5B	40ft-3VL-LWC-50LL-15SD	W18X35 (14) c=1.50"	0.75	3	110	6.25	4	510	17.7	120	138.55	10.3	28.8	40	326.9	388.4	2307	4.63	8.85	0.245	278.25	249	184.98	38.5	22.2	298700	899878	14790000	792080	8.65E-07	1.61E-05	339.5	488.5	488.9	65.9	
6A	45ft-3VL-LWC-100LL-15SD	W18x40 (26) c=2"	0.75	3	110	6.25	4	612	17.9	120	275.9	11.8	46.8	45	500.3	512.4	2307	4.63	8.95	0.245	435.84	294	335.95	57.0	13.7	342200	899878	17748000	792080	7.32E-07	1.40E-05	403.2	568.0	572.5	68.3	
6B	45ft-3VL-LWC-50LL-15SD	W18X40 (16) c=2"	0.75	3	110	6.25	4	612	17.9	120	169.77	11.8	28.8	45	409.1	451.9	2307	4.63	8.95	0.245	321.92	294	250.99	42.5	18.4	342200	899878	17748000	792080	7.32E-07	1.40E-05	403.2	568.0	572.5	68.3	
7A	50ft-3VL-LWC-100LL-15SD	W21x44 (30) c=2.25"	0.75	3	110	6.25	4	843	20.7	120	318.3	13.0	49.0	50	606.3	637.5	2307	4.63	10.35	0.245	536.82	358	376.24	57.9	13.6	377000	899878	24447000	792080	5.93E-07	1.26E-05	445.7	692.9	689.5	68.6	
7B	50ft-3VL-LWC-50LL-15SD	W21X44 (18) c=2.25"	0.75	3	110	6.25	4	843	20.7	120	190.99	13.0	29.4	50	500.2	554.5	2307	4.63	10.35	0.245	384.16	358	287.76	44.3	17.8	377000	899878	24447000	792080	5.93E-07	1.26E-05	445.7	692.9	689.5	68.6	
8A	55ft-3VL-LWC-100LL-15SD	W24x55 (24) c=2.0"	0.75	3	110	6.25	4	1350	23.6	120	254.7	16.2	31.4	55	725.2	781.3	2307	4.63	11.8	0.245	551.67	503	381.63	47.0	14.8	469800	899878	39150000	792080	4.11E-07	9.99E-06	530.5	935.6	928.8	65.5	
8B	55ft-3VL-LWC-50LL-15SD	W24X55 (20) c=2.0"	0.75	3	110	6.25	4	1350	23.6	120	212.21	16.2	26.2	55	603.5	744.48	2307	4.63	11.8	0.245	493.59	503	292.61	36.1	19.3	469800	899878	39150000	792080	4.11E-07	9.99E-06	530.5	935.6	928.8	65.5	
9A	60ft-3VL-LWC-100LL-15SD	W24x62 (48) c= 2.5"	0.75	3	110	6.25	4	1550	23.7	120	509.3	18.2	56.0	60	852.9	1015.3	2307	4.63	11.85	0.245	924.03	574	458.36	50.4	13.4	527800	899878	44950000	792080	3.60E-07	8.94E-06	594.2	1049.7	1042.6	65.3	
9B	60ft-3VL-LWC-50LL-15SD	W27X84 (20) c=1.5"	0.75	3	110	6.25	4	2850	26.7	120	212.21	24.7	17.1	60	727.1	1190.2	2307	4.63	13.35	0.245	709.56	915	222.74	18.0	27.6	716300	899878	82650000	792080	2.15E-07	6.38E-06	698.2	1513.3	1519.1	56.3	v
10A	65ft-3VL-LWC-100LL-15SD	W30x90 (22) c=1.50"	0.75	3	110	6.25	4	3610	29.5	120	233.43	26.4	17.7	65	1004.3	1381.63	2307	4.63	14.75	0.245	812.67	1060	338.14	25.6	19.7	765600	899878	104690000	792080	1.84E-07	5.98E-06	740.7	1745.3	1741.0	56.1	
10B	65ft-3VL-LWC-50LL-15SD	W30x90 (22) c=1.5"	0.75	3	110	6.25	4	3610	29.5	120	233.43	26.4	17.6	65	405.2	1381.63	2307	4.63	14.75	0.245	812.67	1060	10.79	0.8	618.3	765600	899878	104690000	792080	1.84E-07	5.98E-06	740.6	1745.3	1740.8	56.1	v
11A	70ft-3VL-LWC-100LL-15SD	W30x116 (24) c=1.5"	0.75	3	110	6.25	4	4930	30	120	254.66	34.2	19.2	70	1169.4	1776.39	2307	4.63	15	0.245	985.14	1420	347.85	26.2	20.6	991800	899878	142970000	792080	1.37E-07	4.80E-06	896.7	2247.0	2254.5	67.6	
11B	70ft-3VL-LWC-50LL-15SD	W30x116 (24) c=1.5"	0.75	3	110	6.25	4	4930	30	120	254.66	34.2	19.2	70	491.5	1776.39	2307	4.63	15	0.245	985.14	1420	5.00	0.4	1435.3	991800	899878	142970000	792080	1.37E-07	4.80E-06	896.7	2247.0	2254.5	67.6	v
12A	20ft-3VL-NWC-100LL-15SD	W12x19 (12)	0.75	3	150	7.5	4	130	12	60	129.2	5.57	46.4	20	136.4	194.9	3674	5.25	6	0.245	N/A	92.6	N/A	46.4	20.0	161530	992043	3770000	1674073	2.07E-06	3.04E-05			N/A		
12B	20ft-3VL-NWC-50LL-15SD	W12X19 (8)	0.75	3	150	7.5	4	130	12	60	86.15	5.57	30.9	20	108.4	167.51	3674	5.25	6	0.245	N/A	92.6	N/A	30.9	23.8	161530	992043	3770000	1674073	2.07E-06	3.04E-05			N/A		
13A	25ft-3VL-NWC-100LL-15SD	W16x26 (10)	0.75	3	150	7.5	4	301	15.7	75	107.69	7.7	28.0	25	203.9	270.75	3674	5.25	7.85	0.245	257.92	166	52.73	13.7	61.2	222720	1240054	8729000	2092591	1.21E-06	2.12E-05	150.8	302.0	300.3	39.3	
13B	25ft-3VL-NWC-50LL-15SD	W16x26 (10)	0.75	3	150	7.5	4	301	15.7	75	107.69	7.7	28.0	25	165.1	270.75	3674	5.25	7.85	0.245	257.92	166	13.26	3.5	193.5	222720	1240054	8729000	2092591	1.21E-06	2.12E-05	150.8	302.0	300.3	39.3	
14A	30ft-3VL-NWC-100LL-15SD	W16X26 (12) C=1.25"	0.75	3	150	7.5	4	301	15.7	90	129.2	7.7	33.7	30	283.1	287.6	3674	5.25	7.85	0.245	259.02	166	153.63	40.1	25.2	222720	1488065	8729000	2511110	1.17E-06	2.04E-05	215.4	339.7	344.0	56.1	
14B	30ft-3VL-NWC-50LL-15SD	W16X26 (10) C=1.25"	0.75	3	150	7.5	4	301	15.7	90	107.7	7.7	28.0	30	232.5	286.9	3674	5.25	7.85	0.245	237.82	166	102.31	26.6	30.1	222720	1488065	8729000	2511110	1.17E-06	2.04E-05	215.4	339.7	344.0	56.1	
15A	35ft-3VL-NWC-100LL-15SD	W18x35 (12) c=1.25"	0.75	3	150	7.5	4	510	17.7	105	129.2	10.3	25.1	35	375.9	385.6	3674	5.25	8.85	0.245	303.55	249	196.78	38.2	22.9	298700	1736076	14790000	2929628	7.96E-07	1.51E-05	323.1	510.4	511.1	62.7	
15B	35ft-3VL-NWC-50LL-15SD	W18x35 (12) c=1.25"	0.75	3	150	7.5	4	510	17.7	105	129.2	10.3	25.1	35	312.6	385.3	3674	5.25	8.85	0.245	303.55	249	137.65	26.7	26.1	298700	1736076	14790000	2929628	7.96E-07	1.51E-05	323.1	510.4	511.1	62.7	
16A	40ft-3VL-NWC-100LL-15SD	W21x44 (14) c=1.5"	0.75	3	150	7.5	4	843	20.7	120	150.8	13.0	23.2	40	481.5	534.5	3674	5.25	10.35	0.245	385.03	358	231.61	35.6	22.3	377000	1984087	24447000	3348146	5.61E-07	1.19E-05	445.8	734.8	737.2	68.6	
16B	40ft-3VL-NWC-50LL-15SD	W21x44 (14) c=1.5"	0.75	3	150	7.5	4	843	20.7	120	150.8	13.0	23.2	40	404.6	534.5	3674	5.25	10.35	0.245	385.03	358	167.19	25.7	24.5	377000	1984087	24447000	3348146	5.61E-07	1.19E-05	445.8	734.8	737.2	68.6	
17A	45ft-3VL-NWC-100LL-15SD	W21x50 (16) c=2"	0.75	3	150	7.5	4	984	20.8	120	172.3	14.7	23.4	45	598.8	611.6	3674	5.25	10.4	0.245	416.30	413	323.51	43.9	17.9	426300	1984087	28536000	3348146	4.91E-07	1.05E-05	519.0	837.9	834.8	70.6	
17B	45ft-3VL-NWC-50LL-15SD	W21x50 (16) c=2"	0.75	3	150	7.5	4	984	20.8	120	172.3	14.7	23.4	45	507.7	611.6	3674	5.25	10.4	0.245	416.30	413	248.03	33.7	18.6	426300	1984087	28536000	3348146	4.91E-07	1.05E-05	488.9	815.6	798.4	70.6	
18A	50ft-3VL-NWC-100LL-15SD	W24x55 (18) c=2.25"	0.75	3	150	7.5	4	1350	23.6	120	193.8	16.2	23.9	50	728.4	745.5	3674	5.25	11.8	0.245	486.82	503	375.69	46.3	17.2	469800	1984087	39150000	3348146	4.01E-07	9.47E-06	598.7	1018.4	1024.6	73.9	
18B	50ft-3VL-NWC-50LL-15SD	W24x55 (18) c=2.25"	0.75	3	150	7.5	4	1350	23.6	120	193.83	16.2	23.9	50	622.3	745.54	3674	5.25	11.8	0.245	486.86	503	295.81	36.5	17.3	469800	1984087	39150000	3348146	4.01E-07	9.47E-06	598.7	1018.4	1024.6	73.9	
19A	55ft-3VL-NWC-100LL-15SD	W24X68 (20) c=2.50"	0.75	3	150	7.5	4	1830	23.7	120	215.37	20.1	21.4	55	874	929.78	3674	5.25	11.85	0.245	571.94	664	435.24	43.3	16.3	582900	1984087	53070000	3348146	3.03E-07	7.40E-06	702.1	1239.1	1240.6	69.9	
19B	55ft-3VL-NWC-50LL-15SD	W24X68 (20) c=2.50"	0.75	3	150	7.5	4	1830	23.7	120	215.37	20.1	21.4	55	752.3	929.78	3674	5.25	11.85	0.245	571.94	664	346.65	34.5	16.3	582900	1984087	53070000	3348146	3.03E-07	7.40E-06	702.1	1239.1	1240.6	69.9	
20A	60ft-3VL-NWC-100LL-15SD	W27x84 (20) c=2.25"	0.75	3	150	7.5	4	2850	26.7	120	215.4	24.7	17.4	60	1034.9	1213.8	3674	5.25	13.35	0.245	686.44	915	441.61	35.7	17.5	716300	1984087	82650000	3348146	2.16E-07	5.92E-06	842.1	1644.3	1651.8	67.9	
20B	60ft-3VL-NWC-50LL-15SD	W30x90 (20) c=1.75"	0.75	3	150	7.5	4	3610	29.5	120	215.4	26.4	16.3	60	900	1380.95	3674	5.25	14.75	0.245	775.14	1060	289.94	22.0	21.2	765600	1984087	104690000	3348146	1.85E-07	5.51E-06	872.3	1874.0	1875.4	66.1	v
21A	65ft-3VL-NWC-100LL-15SD	W30x108 (22) c=2.00"	0.75	3	150	7.5	4	4470	29.8	120	236.9	31.7	15.0	65	1215.1	1649.7	3674	5.25	14.9	0.245	875.74	1300	433.70	27.4	19.3	919300	1984087	129630000	3348146	1.52E-07	4.65E-06	1035.9	2244.8	2253.5	65.4	
21B	65ft-3VL-NWC-50LL-15SD	W30x108 (22) c=2.00"	0.75	3	150	7.5	4	4470	29.8	120	236.91	31.7	15.0	60	650.1	1649.7	3674	5.25	14.9	0.245	914.70	1300	83.46	5.3	73.8	919300	1984087	129630000	3348146	1.52E-07	4.65E-06	1005.8	2232.3	2240.5	63.5	v
22A	70ft-3VL-NWC-100LL-15SD	W33x118 (24) c=2.0"	0.75	3	150	7.5	4	5900	32.9	120	258.45	34.7	18.8	70	1401.9	1971.95	3674	5.25	16.45	0.245	1019.04	1560	460.18	33.5	19.6	1006300	1984087	171100000	3348146	1.24E-07	4.20E-06	1115.6	2641.5	2645.9	64.3	
22B	70ft-3VL-NWC-50LL-15SD	W33x118 (24) c=2.0"	0.75	3	150	7.5	4	5900	32.9	120	258.45	34.7	14.9	60	762.7	1971.95	3674	5.25	16.45	0.245	1107.12	1560	76.97	4.4	80.0	1006300	1984087	171100000	3348146	1.24E-07	4.20E-06	1055.3	2617.1	2619.5	60.8	v
23A	20ft-2VL-LWC-100LL-15SD	W12X19 (8)	0.75	2	110	5.25	4	130	12	60	84.89	5.57	30.5	20	114.7	152.3	2307	3.63	6	0.245	N/A	92.6	N/A	30.5	24.2	161530	449939	3770000	396040	2.31E-06	3.07E-05			N/A		
23B	20ft-2VL-LWC-50LL-15SD	W12x19 (8)	0.75	2	110	5.25	4	130	12	60	84.89	5.57	30.8	20	86.7	152.3	2307	3.63	6	0.245	N/A	92.6	N/A	30.8	24.2	161530	449939	3770000	396040	2.31E-06	3.07E-05			N/A		
24A	25ft-2VL-LWC-100LL-15SD	W14x22 (12)	0.75	2	110	5.25	4	199	13.7	75	127.33	6.49	23.2	25	169.6	210.9	2307	3.63	6.85	0.245	N/A	125	N/A	23.2	20.1	188210	562424	5771000	495050	1.67E-06	2.46E-05			N/A		
24B	25ft-2VL-LWC-50LL-15SD	W14x22 (10)	0.75	2	110	5.25	4	199	13.7	75	106.11	6.49	32.7	25	130.8	200.4	2307	3.63	6.85	0.245	197.96	125	24.98	7.7	102.7	188210	562424	5771000	495050	1.67E-06	2.46E-05	127.3	210.9	215.5	39.2	
25A	30ft-2VL-LWC-100LL-15SD	W16X31 (12)	0.75	2	110	5.25	4	375	15.9	90	127.33	9.13	27.9	30	234.9	305.1	2307	3.63	7.95	0.245	272.22	203	87.80	19.2	35.1	264770	674908	10875000	594060	1.01E-06	1.69E-05	191.0	338.0	332.3	41.8	
25B	30ft-2VL-LWC-50LL-15SD	W16x26 (14)	0.75	2	110	5.25	4	301	15.7	90	148.55	7.7	38.7	30	183.6	276.0	2307	3.63	7.85	0.245	260.98	166	64.24	16.7	47.9	223300	674908	8729000	594060	1.23E-06	2.01E-05	191.0	294.4	299.9	49.7	x
26A	35ft-2VL-LWC-100LL-15SD	W18x35 (12) c=0.75"	0.75	2	110	5.25	4	510	17.7	105	127.33	10.3	24.7	35	309.4	362.4	2307	3.63	8.85	0.245	293.59	249	142.76	27.7	25.2	298700	787393	14790000	693070	8.06E-07	1.47E-05	254.7	431.2	424.0	49.5	
26B	35ft-2VL-LWC-50LL-15SD	W16x26 (12) c=1.25"	0.75	2	110	5.25	4	301	15.7	105	127.33	7.7	33.2	35	244.4	265.0	2307	3.63	7.85	0.245	223.96	203	149.77	39.0	24.0	223300	787393	8729000	693070	1.22E-06	1.97E-05	220.2	303.0	308.6	55.3	x
27A	40ft-2VL-LWC-100LL-15SD	W18X35 (16) c=1.25"	0.75	2	110	5.25	4	510	17.7	120	169.77	10.3	33.0	40	392.3	390.6	2307	3.63	8.85	0.245	316.03	249	244.91	47.5	16.8	298700	899878	14790000	792080	8.01E-07	1.44E-05	297.1	447.8	445.3	57.7	
27B	40ft-2VL-LWC-50LL-15SD	W16x31 (16) c=1.75"	0.75	2	110	5.25	4	375	15.9	120	169.77	9.1	37.2	40	314.5	329.2	2307	3.63	7.95	0.245	273.67	203	213.72	46.8	19.2	263900	899878	10875000	792080	9.92E-07	1.64E-05	275.9	371.7	372.2	60.4	
28A	45ft-2VL-LWC-100LL-15SD	W18x40 (36) c=1.75"	0.75	2	110	5.25	4	612	17.9	120	381.98	11.8	64.7	45	485.8	530.4	2307	3.63	8.95	0.245	N/A	294	N/A	64.7	12.1	342200	899878	17748000	792080	6.78E-07	1.26E-05			N/A		
28B	45ft-2VL-LWC-50LL-15SD	W18x40 (16) c=1.75"	0.75	2	110	5.25	4	612	17.9	120	169.77	11.8	28.8	45	394.7	439.2	2307	3.63	8.95	0.245	327.66	294	234.12	39.7	19.7	342200	899878	17748000	792080	6.78E-07	1.26E-05	360.8	522.9	526.6	61.1	
29A	50ft-2VL-LWC-100LL-15SD	W21x44 (36) c=2"	0.75	2	110	5.25	4	843	20.7	120	381.98	13.0	58.8	50	588.5	637.6	2307	3.63	10.35	0.245	612.55	358	361.39	55.6	14.2	377000	899878	24447000	792080	5.54E-07	1.15E-05	403.2	645.0	637.3	62.0	
29B	50ft-2VL-LWC-50LL-15SD	W21x44 (18) c=2"	0.75	2	110	5.25	4	843	20.7	120	190.99	13.0	29.4	50	482.4	540.1	2307	3.63	10.35	0.245	389.39	358	270.59	41.6	19.0	377000	899878	24447000	792080	5.54E-07	1.15E-05	403.3	645.0	637.5	62.0	
30A	55ft-2VL-LWC-100LL-15SD	W24x55 (30) c=2"	0.75	2	110	5.25	4	1350	23.6	120	318.32	16.2	39.3	55	703.7	805.63	2307	3.63	11.8	0.245	643.08	503	363.58	44.9	15.5	469800	899878	39150000	792080	3.86E-07	9.20E-06	509.3	888.8	898.9	62.9	
30B	55ft-2VL-LWC-50LL-15SD	W24x55 (20) c=1.75"	0.75	2	110	5.25	4	1350	23.6	120	212.21	16.2	26.2	55	582	728.56	2307	3.63	11.8	0.245	500.94	503	272.72	33.7	20.7	469800	899878	39150000	792080	3.86E-07	9.20E-06	509.3	888.8	898.9	62.9	
31A	60ft-2VL-LWC-100LL-15SD	W24x55 (62) c=2.75"	0.75	2	110	5.25	4	1350	23.6	120	652.03	16.2	80.5	60	823.6	933.21	2307	3.63	11.8	0.245	N/A	503	N/A	80.5	9.4	469800	899878	39150000	792080	3.86E-07	9.20E-06			N/A		
31B	60ft-2VL-LWC-50LL-15SD	W27x84 (20) c=1.25"	0.75	2	110	5.25	4	2850	26.7	120	212.21	24.7	17.1	60	701.5	1174.28	2307	3.63	13.35	0.245	726.78	915	196.87	15.9	31.3	716300	899878	82650000	792080	2.03E-07	5.96E-06	652.0	1446.6	1451.7	52.6	v
32A	65ft-2VL-LWC-100LL-15SD	W30x90 (22) c=1.50"	0.75	2	110	5.25	4	3610	29.5	120	233.43	26.4	18.9	65	965.5	1364.12	2307	3.63	14.75	0.245	829.92	1060	308.16	25.0	21.6	765600	899878	104690000	792080	1.74E-07	5.62E-06	694.5	1675.7	1666.4	52.6	
32B	65ft-2VL-LWC-50LL-15SD	W30x90 (22) c=1.50"	0.75	2	110	5.25	4	3610	29.5	120	233.43	26.4	17.6	65	370.3	1364.12	2307	3.63	14.75	0.245	829.92	1060	N/A	17.6	28.6	765600	899878	104690000	792080	1.74E-07	5.62E-06	694.5	1675.7	1666.3	52.6	v
33A	70ft-2VL-LWC-100LL-15SD	W30x116 (24) c=1.5"	0.75	2	110	5.25	4	4930	30	120	254.66	34.2	19.2	70	1111	1757.3	2307	3.63	15	0.245	1008.61	1420	306.69	23.1	23.4	991800	899878	142970000	792080	1.30E-07	4.53E-06	850.5	2166.3	2181.2	64.1	
33B	70ft-2VL-LWC-50LL-15SD	W30x116 (24) c=1.5"	0.75	2	110	5.25	4	4930	30	120	254.66	34.2	19.2	70	450.8	1757.3	2307	3.63	15	0.245	1008.61	1420	N/A	19.2	28.2	991800	899878	142970000	792080	1.30E-07	4.53E-06	850.5	2166.3	2181.2	64.1	v
34A	20 ft-2VL-NWC-100LL-15SD	W12x16 (12)	0.75	2	150	4.5	4	103	12	60	127.33	4.71	54.1	20	121.4	164	3674	3.25	6	0.245	N/A	75.4	N/A	54.1	16.1	136590	551135	2987000	287050	2.83E-06	3.53E-05			N/A		
34B	20 ft-2VL-NWC-50LL-15SD	W12x16 (8)	0.75	2	150	4.5	4	103	12	60	84.89	4.71	36.0	20	93.4	141.22	3674	3.25	6	0.245	141.06	75.4	17.02	7.2	120.5	136590	551135	2987000	287050	2.83E-06	3.53E-05	84.9	141.2	141.1	36.0	
35A	25 ft-2VL-NWC-100LL-15SD	W16x26 (10)	0.75	2	150	4.5	4	301	15.7	75	106.11	7.7	27.6	25	180.7	261.53	3674	3.25	7.85	0.245	245.94	166	33.41	8.7	76.8	223300	688919	8729000	358812	1.22E-06	1.95E-05	148.6	289.4	284.0	38.7	
35B	25 ft-2VL-NWC-50LL-15SD	W16x26 (10)	0.75	2	150	4.5	4	301	15.7	75	106.11	7.7	27.6	25	141.9	261.53	3674	3.25	7.85	0.245	245.94	166	N/A	27.6	24.2	223300	688919	8729000	358812	1.22E-06	1.95E-05	148.6	289.4	284.1	38.7	
36A	30 ft-2VL-NWC-100LL-15SD	W16x26 (10)	0.75	2	150	4.5	4	301	15.7	90	106.11	7.7	27.6	30	249.7	261.81	3674	3.25	7.85	0.245	220.85	166	138.58	36.1	22.2	223300	826703	8729000	430574	1.21E-06	1.91E-05	233.4	331.7	334.0	60.8	
36B	30 ft-2VL-NWC-50LL-15SD	W16X26 (10)	0.75	2	150	4.5	4	301	15.7	90	106.11	7.7	27.6	30	199.1	261.81	3674	3.25	7.85	0.245	220.85	166	81.62	21.3	37.7	223300	826703	8729000	430574	1.21E-06	1.91E-05	233.4	331.7	334.0	60.8	
37A	35 ft-2VL-NWC-100LL-15SD	W16x31 (14) c=1.25"	0.75	2	150	4.5	4	375	15.9	105	148.55	9.1	32.5	35	329.7	331.67	3674	3.25	7.95	0.245	268.12	203	216.53	47.4	16.6	263900	964487	10875000	502337	9.84E-07	1.59E-05	297.1	406.1	402.7	65.1	
37B	35 ft-2VL-NWC-50LL-15SD	W16x31 (12) c=1.25"	0.75	2	150	4.5	4	375	15.9	105	127.33	9.1	27.9	35	266.4	317.27	3674	3.25	7.95	0.245	248.90	203	146.65	32.1	24.5	263900	964487	10875000	502337	9.84E-07	1.59E-05	297.1	406.1	402.7	65.1	
38A	40 ft-2VL-NWC-100LL-15SD	W18x35 (18) c=1.25"	0.75	2	150	4.5	4	510	17.7	120	190.99	10.3	37.1	40	419.8	420.67	3674	3.25	8.85	0.245	334.13	249	278.01	54.0	14.8	298700	1102270	14790000	574099	7.88E-07	1.38E-05	360.8	504.3	501.3	70.1	
38B	40 ft-2VL-NWC-50LL-15SD	W18x35 (14) c=1.50"	0.75	2	150	4.5	4	510	17.7	120	148.55	10.3	28.8	40	343	391.15	3674	3.25	8.85	0.245	292.34	249	200.00	38.8	20.5	298700	1102270	14790000	574099	7.88E-07	1.38E-05	360.8	504.3	501.3	70.1	
39A	45 ft-2VL-NWC-100LL-15SD	W21x44 (16) c=1.25"	0.75	2	150	4.5	4	843	20.7	120	169.77	13	26.1	45	521.9	540.13	3674	3.25	10.35	0.245	380.57	358	294.47	45.3	15.7	377000	1102270	24447000	574099	5.44E-07	1.10E-05	466.9	710.3	717.3	71.8	
39B	45 ft-2VL-NWC-50LL-15SD	W21x44 (16) c=1.50"	0.75	2	150	4.5	4	843	20.7	120	169.77	13	26.1	45	430.7	540.13	3674	3.25	10.35	0.245	380.57	358	214.00	32.9	21.6	377000	1102270	24447000	574099	5.44E-07	1.10E-05	466.9	710.3	717.3	71.8	
40A	50 ft-2VL-NWC-100LL-15SD	W21x48 (22) c=1.75"	0.75	2	150	4.5	4	959	20.6	120	233.43	14.1	33.1	50	632.9	630.55	3674	3.25	10.3	0.245	462.95	398	380.28	53.9	13.5	408900	1102270	27811000	574099	4.77E-07	9.82E-06	488.1	758.6	757.7	69.2	
40B	50 ft-2VL-NWC-50LL-15SD	W24x55 (18) c=1.50"	0.75	2	150	4.5	4	1350	23.6	120	190.99	16.2	23.6	50	529.5	728.24	3674	3.25	11.8	0.245	490.71	503	220.89	27.3	23.2	469800	1102270	39150000	574099	3.79E-07	8.74E-06	545.9	952.0	951.2	67.4	V
41A	55 ft-2VL-NWC-100LL-15SD	W24x55 (24) c=1.75"	0.75	2	150	4.5	4	1350	23.6	120	254.66	16.2	31.4	55	755.7	786.08	3674	3.25	11.8	0.245	551.22	503	412.28	50.9	13.7	469800	1102270	39150000	574099	3.79E-07	8.74E-06	573.0	963.1	964.2	70.7	
41B	55 ft-2VL-NWC-50LL-15SD	W24x68 (20) c=1.75"	0.75	2	150	4.5	4	1830	23.7	120	212.21	20.1	21.1	55	640	910.63	3674	3.25	11.85	0.245	588.73	664	249.54	24.8	22.6	582900	1102270	53070000	574099	2.81E-07	6.87E-06	619.2	1153.7	1147.7	61.6	V
42A	60 ft-2VL-NWC-100LL-15SD	W24x68 (26) c=2.0"	0.75	2	150	4.5	4	1830	23.7	120	275.88	20.1	27.5	60	892.6	967.31	3674	3.25	11.85	0.245	651.41	664	451.48	44.9	13.6	582900	1102270	53070000	574099	2.81E-07	6.87E-06	652.0	1166.9	1168.0	64.9	
42B	60 ft-2VL-NWC-50LL-15SD	W27x84 (20) c=1.50"	0.75	2	150	4.5	4	2850	26.7	120	212.21	24.7	17.1	60	763.3	1194.17	3674	3.25	13.35	0.245	720.53	915	239.22	19.3	25.7	716300	1102270	82650000	574099	1.99E-07	5.61E-06	729.0	1538.5	1538.8	58.8	V
43A	65 ft-2VL-NWC-100LL-15SD	W30x90 (22) c=1.75"	0.75	2	150	4.5	4	3610	29.5	120	233.43	26.4	17.7	65	1043.3	1386.01	3674	3.25	14.75	0.245	820.35	1060	361.52	27.4	18.4	765600	1102270	104690000	574099	1.71E-07	5.29E-06	786.8	1777.0	1783.6	59.6	
43B	65 ft-2VL-NWC-50LL-15SD	W30x90 (22) c=1.75"	0.75	2	150	4.5	4	3610	29.5	120	233.43	26.4	17.6	65	455.1	1368.01	3674	3.25	14.75	0.245	820.35	1060	23.59	1.8	282.8	765600	1102270	104690000	574099	1.71E-07	5.29E-06	786.8	1777.0	1783.6	59.6	V
44A	70 ft-2VL-NWC-100LL-15SD	W33x118 (24) c=1.5"	0.75	2	150	4.5	4	5900	32.9	120	254.66	34.7	14.7	70	1195.2	1947.55	3674	3.25	16.45	0.245	1092.42	1560	305.05	17.6	23.5	1006300	1102270	171100000	574099	1.15E-07	4.16E-06	942.8	2498.5	2496.3	54.3	
44B	70 ft-2VL-NWC-50LL-15SD	W33x118 (24) c=1.5"	0.75	2	150	4.5	4	5900	32.9	120	254.66	34.7	14.7	70	550.5	1947.55	3674	3.25	16.45	0.245	1092.42	1560	N/A	14.7	28.2	1006300	1102270	171100000	574099	1.15E-07	4.16E-06	942.8	2498.5	2496.2	54.3	V
A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20	A21	A25	A25X	A26	A27	A27x	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	NOTE AQ

TABLE NOTES:

Deflection limits: L/240 (DL), L/360 (LL), L/200 (DPC)

3VL 7 1/2" (NW, 115 pcf), f'c=4 ksi

Minimum camber: 3/4", minimum cambered beam sizes: W8x21, W10x26, W12x22, W14x26 or W16x26

Maximum Stud Spacing = 36"

Note: Qmax is taken as ΣQ_n when computing S_{max} if stud fracture moment governs. Else, it is the min. of ΣQ_{est} and ΣQ_n.

COLUMN NOTES:

2A. W12x19 (12) c=3/4" could not be cambered. Therefore, W14x22 (18) is used as the minimum size.
10A. Changed to W30x90 (22) c= 1.50" due to vibration performance.
10B. Changed to W30x90 (22) c= 1.50" due to vibration performance.
11A. Changed to W30x116 (24) c=1.5" due to vibration performance
11BA. Changed to W30x116 (24) c=1.5" due to vibration performance
12B. The inability to camber W12x16 (6) c=3/4", caused the use of W12x19 (6)
12A. The inability to camber W12x16 (8) c=3/4", caused the use of W12x19 (14)
13B. W14x22 (8) c=3/4" could not be cambered. Therefore, W16x26 (10) is used instead.
13A. W14x22 (10) c=3/4" could not be cambered. Therefore, W16x26 (8) is used instead.
20B. Changed to W30x90 (2) c=1.75" due to vibration performance.
21A. Changed to W30x108 (22) c=2.00" due to vibration performance
21B. Changed to W30x108 (22) c=2.0" due to vibration performance
22A. Changed to W33x118 (24) c=2.0" due to vibration performance
22B. Changed to W33x118 (24) c=2.0" due to vibration performance
23B. W10x12 (16) c=3/4" could not be cambered. W12x19 (8) is used instead.
23A. W10x12 (16) c=3/4" could not be cambered. W12x19 (8) is used instead.
24B. W12x16 (22) c=3/4" cannot be cambered. Therefore, W14x22 (10) is used instead.
24A. W12x16 (22) c=3/4" cannot be cambered. Therefore, W14x22 (12) is used instead.
25B. W14x22 (24) c=1" cannot be cambered. Therefore, W16x31 (14) is used instead.
27A. W16x31 (52) c=1.75" was changed to W18x35 (22) c=1.25" due to vibration performance.
31B. W24x55 (62) c=2.75" was changed to W27x84 (20) c=1.25" due to vibration performance.
32B. Changed to W30x90 (22) c=1.50" due to vibration performance.
32A. Changed to W30x90 (22) c=1.50" due to vibration performance.
33B. Changed to W30x116(24) c= 1.5" due to vibration performance.
33A. Changed to W30x116(24) c= 1.5" due to vibration performance.
40B. Changed to W24x55 (18) c=1.5" due to vibration performance.
41B. Changed to W24x68 (20) c=1.75" due to vibration performance.
42B. Changed to W27x84 (20) c=1.5" due to vibration performance.
43B. Changed to W30x90 (22) c=1.75" due to vibration performance.
43A. Changed to W30x90 (22) c=1.75" due to vibration performance.
44B. Changed to W33x118 (24) c=1.50" due to vibration performance.
44A. Changed to W33x118 (24) c=1.50" due to vibration performance.
A3. Number of Studs is fewest required while still passing the bending /deflection /stud spacing requirement, but ignoring the 25% composite limit.
A12. Determined based on note A3
A14. Determined based on note A3
A17. Determined based on note A3
A22X. Reduce the number of studs further such that phi*Mn from RPA is about equal to Mu.
A25. Value is RED when phi*Mfr < phi*Mp.
A34. This value changes by the number of studs, increase until Col A35 is approximately equal to the phi*Mn value given by RPA.
AQ. V indicates beam size increased due to vibration performance.

Appendix B – Girder Data (Table 4)

The same explanation of table cells applies as for Appendix A, except for the following are the variables not appearing in Appendix A:

A18 factor representing the ratio of moment of inertia of a slab with ribs parallel to the beam to the moment ratio of a solid slab with the same total thickness

TABLE 4

No.	Scenario	Beam Size	d_s (in.)	h_r (in.)	w_c (pcf)	t_s (in.)	f'_c (ksi)	I_x (in.^{4})	d (in.)	b_{eff} (in.)	ΣQ_n (kip)	A_s (in.^{2})	%C	L (ft)	M_u (kip-ft)	ΦM_n (kip-ft)	R	E_c (ksi)	h_c (in.)
45	20-ft BAYS - 50 psf LL	W18X40 (7/3/7)	0.75	3	110	6.25	4	612	17.9	90	169.80	11.8	25.3	30	327.3	451.1	0.66	2307	3.67
46	60-ft BAYS - 50 psf LL	W24x76 (5/3/5)	0.75	3	110	6.25	4	2100	23.9	90	127.3	22.4	10.7	30	902.7	911.0	0.66	2307	3.67
47	20ft-BAYS - 50 psf LL	W21x50 (3/3/3) c=3/4"	0.75	3	150	7.5	4	984	20.8	90	86.2	14.7	8.8	30	404.6	519.8	0.67	3674	4.34
48	60-ft BAYS - 50 psf LL	W30x90 (3/3/3)	0.75	3	150	7.5	4	3610	29.5	90	86.15	26.3	4.9	30	1147.3	1199.4	0.67	3674	4.34
49	20 ft BAYS - 50 psf LL	W18x40 (5/3/5)	0.75	2	110	5.25	4	612	17.9	90	127.30	26.3	18.1	30	315.4	409.7	0.68	2307	3.02
50	60-ft BAYS - 50 psf LL	W24x68 (12/4/12)	0.75	2	110	5.25	4	1830	23.7	90	297.10	20.1	25.7	30	862.6	953.9	0.68	2307	3.02
51	20-ft BAYS - 50 psf LL	W18x40 (3/3/3) c=3/4"	0.75	2	150	5.25	4	612	17.9	90	169.8	11.8	10.8	30	343.4	384.3	0.71	3674	3.67
52	60-ft BAYS - 50 psf LL	W24x76 (7/3/7) c=3/4"	0.75	2	150	5.25	4	2100	23.9	90	169.8	22.4	13.3	30	955.7	959.9	0.71	3674	3.67
53	20-ft BAYS - 100 psf LL	W18X40 (54)	0.75	3	110	6.25	3	612	17.9	90	461.80	11.8	52.3	30	404.6	576.7	0.66	1998	3.67
54	60-ft BAYS - 100 psf LL	W24x76 (14/3/14)	0.75	3	110	6.25	3	2100	23.9	90	256.5	22.4	32.1	30	1025.7	1036.4	0.66	1998	3.67
55	20ft-BAYS - 100 psf LL	W21x48 (3/3/3) c=3/4"	0.75	3	150	7.5	3	959	20.6	90	86.2	14.1	9.2	30	481.9	505.7	0.67	3182	4.34
56	60-ft BAYS - 100 psf LL	W30x90 (6/3/6)	0.75	3	150	7.5	3	3610	29.5	90	150.8	26.3	12.5	30	1270.2	1292.2	0.67	3182	4.34
57	20 ft BAYS - 100 psf LL	W16x36 (13/3/13) c=3/4"	0.75	2	110	5.25	3	448	15.9	90	239.40	10.6	42.1	30	393.3	396.5	0.68	1998	3.02
58	60-ft BAYS - 100 psf LL	W24x68 (66)	0.75	2	110	5.25	3	1830	23.7	90	564.40	20.1	50.5	30	862.6	1055.5	0.68	1998	3.02
59	20-ft BAYS - 100 psf LL	W18x40 (7/3/7) c=3/4"	0.75	2	150	5.25	3	612	17.9	90	136.8	11.8	20.3	30	420.7	428.6	0.71	3182	3.67
60	60-ft BAYS - 100 psf LL	W24x76 (17/3/17) c=3/4"	0.75	2	150	5.25	3	2100	23.9	90	307.9	22.4	28.2	30	955.7	959.9	0.71	3182	3.67
A1	A2	A3	A4	A5	A6	A7	A8	A9	A10	A11	A12	A13	A14	A15	A16	A17	A18	A19	A20

No.	h_s (in.)	S_u (in.)	ΣQ_{est} (kip)	Points A through D									(Point F)			
				ΦM_{fr} (kip-ft)	$\Sigma Q_{n,req.}$ (kip)	$\%C_{req.}$	EA_s (kips)	EA_c (kips)	EI_s (k/in.^{2})	EI_c (k/in.^{2})	K_1 (1/kips)	K_2 (1/kips)	ΣQ_n (kip), $\Phi M_n = \Phi M_{fr}$	ΦM_n (kip-ft)	ΦM_{fr} (kip-ft)	%C, $\Phi M_n = \Phi M_r$
45	8.95	0.245	42.4	741.5	N/A	25.3	342200	986405	17748000	2788459	6.15E-07	1.17E-05	N/A	N/A	N/A	N/A
46	11.95	0.245	127.3	1499.5	N/A	10.7	649600	986405	60900000	2788459	2.45E-07	6.38E-06	N/A	N/A	N/A	N/A
47	10.4	0.245	0.0	896.8	N/A	8.8	426300	1984087	28536000	7789090	4.06E-07	8.83E-06	N/A	N/A	N/A	N/A
48	14.75	0.245	43.1	2000.2	N/A	4.9	762700	1984087	104690000	7789090	1.70E-07	5.06E-06	N/A	N/A	N/A	N/A
49	8.95	0.245	21.2	650.8	N/A	18.1	762700	882573	17748000	1702814	6.15E-07	9.81E-06	N/A	N/A	N/A	N/A
50	11.85	0.245	191.0	1695.2	N/A	25.7	582900	882573	53070000	1702814	2.71E-07	6.89E-06	N/A	N/A	N/A	N/A
51	8.95	0.245	42.4	736.5	N/A	10.8	342200	1405395	17748000	2831160	6.13E-07	1.14E-05	N/A	N/A	N/A	N/A
52	11.95	0.245	169.8	1567.7	N/A	13.3	649600	1405395	60900000	2831160	2.45E-07	6.08E-06	N/A	N/A	N/A	N/A
53	8.95	0.261	119.7	1184.7	N/A	52.3	342200	854252	17748000	2414876	6.26E-07	1.20E-05	N/A	N/A	N/A	N/A
54	11.95	0.261	256.5	1834.0	N/A	32.1	649600	854252	60900000	2414876	2.47E-07	6.56E-06	N/A	N/A	N/A	N/A
55	10.3	0.261	64.6	910.8	N/A	9.2	408900	1718269	27811000	6745550	4.24E-07	9.23E-06	N/A	N/A	N/A	N/A
56	14.75	0.261	129.2	2245.0	N/A	12.5	762700	1718269	104690000	6745550	1.71E-07	5.16E-06	N/A	N/A	N/A	N/A
57	7.95	0.261	239.4	735.1	N/A	42.1	307400	764330	12992000	1474680	7.58E-07	1.29E-05	N/A	N/A	N/A	N/A
58	11.85	0.261	359.2	2295.5	N/A	50.5	582900	764330	53070000	1474680	2.73E-07	7.08E-06	N/A	N/A	N/A	N/A
59	8.95	0.261	136.8	713.1	N/A	20.3	342200	1217108	17748000	2451856	6.25E-07	1.16E-05	N/A	N/A	N/A	N/A
60	11.95	0.261	307.9	1904.8	N/A	28.2	649600	1217108	60900000	2451856	2.47E-07	6.21E-06	N/A	N/A	N/A	N/A
A1	A21	A22	A23	A26	A27	A28	A29	A30	A31	A32	A33	A34	A35	A36	A37	A38

TABLE NOTES:

Deflection limits: L/240 (DL), L/360 (LL), L/200 (DPC)

2VL 5 1/4" (LW, 110 pcf), 2VL 6.5" (NW, 150 pcf), 3VL 7.5" (NWC, 150 PCF), 3VL 6 1/4" (LW, 110 pcf), 3VL 7.5" (NWC, 150 PCF), 50 PSF LL + 15 psf LL for partitions, 100 psf LL

Minimum camber: 3/4", minimum cambered beam sizes: W8x21, W10x26, W12x22, W14x26 or W16x26

Maximum Stud Spacing = 36"

Note: Qmax is taken as ΣQ_n when computing S_{max} if stud fracture moment governs. Else, it is the min. of ΣQ_{est} and ΣQ_n.

COLUMN NOTES:

A18. R is the ratio of the ribbed slab moment of inertia to the moment of inertia of the solid slab with the same thickness.