PGSuper Flexural Design Algorithm Modifications

Version 2.0, March 14, 2008

Change Log

3/14/2008 – rdp – Version 2.0
Added debond design. This work included reorganization of general flow charts, and addition of Appendix B – Debonding Perquisites.

12/14/2007 - R. Brice
-Designer not catching Mr < Mr Min at points other than mid-span.
-Design algorithm was implemented to only consider the mid-span point. I adjusted the algorithm to look at all flexural capacity analysis points.
-Designer was not converging on valid design.
-The case in question was during a compression controlled step in the strand sizing subsystem. The required concrete strength was computed, but was not updated because it was set to something larger by another design step. This indicates that there are way too many strands. I solved this by computing the concrete strength required to make the tension case work, this gets f'c in the ball park, and resetting the number of strands to the initial guess because they are way out of bounds. The design algorithm then restarts and converges on a design.

10/8/2007 – rdp Version 1.0
As-Is For Harped Design

Background

The flexural design algorithm in PGSuper is being modified so that it will be flexible enough to handle both TxDOT and WSDOT design requirements. The algorithm will also be modified to incorporate debond design as well as harped strand design. Note that shear design is not addressed in this document.

This document describes the user input and design algorithms required to make this change happen. Note that other changes have already been incorporated into the program to make this possible. One example is the new strand input UI/implementation.

Organization of This Document

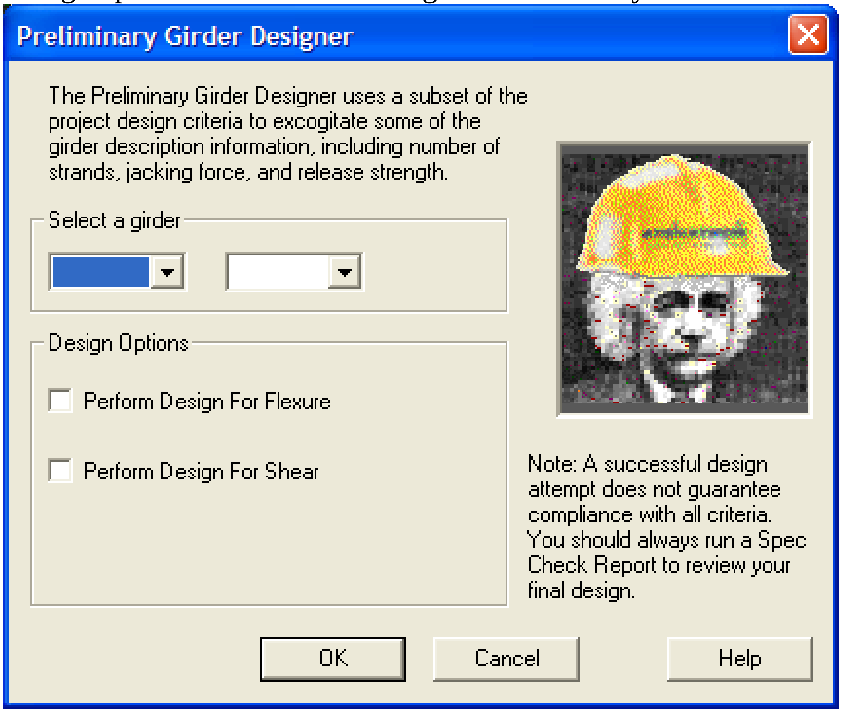
The initial paragraphs of this document are meant to give the user an understanding of the background information for this project, and how the design algorithm will fit into the PGSuper program. However, the "meat" of the information is contained in the detailed flow charts contained in the Appendices. The flowcharts must be reviewed carefully to avoid major problems in the implementation. Apologies for the difficult reading, but in software development, the Devil hides in the details. Perquisite work required to add debonding design is defined in Appendix B. Also note that there is a Glossary of terms in Appendix C.

User Interface Changes

The following is a discussion of various user interface widgets that directly affect the design algorithm.

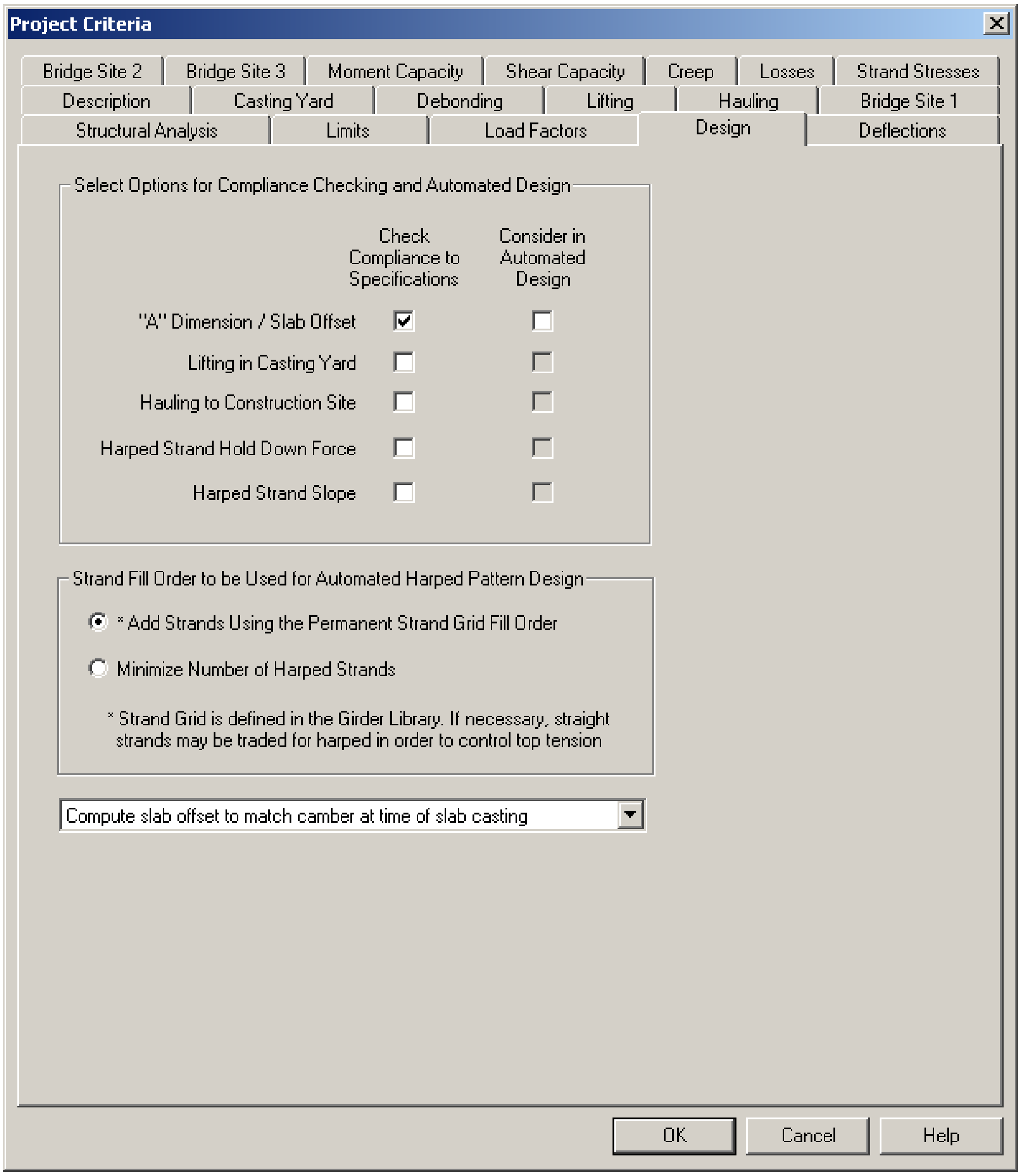
Girder Designer Dialog

The Preliminary Girder Designer dialog (shown below) will remain mostly unchanged. Design options are set in the Design Criteria library



Design Criteria Dialog

Primary control of the design algorithm, and compliance checking is contained in a new tab to be added to the Design Criteria library entry. User's wanting flexural design can now specify whether the algorithm will include the design of the "A" Dimension, Lifting, Hauling, Strand Slope, and Hold Down Force. Note that design cannot be turned on for an item unless compliance checking is also turned on.



"A" Dimension Design

The "A" dimension is the vertical distance between the top of the slab and the top of the girder at the bearing line. If enabled, the "A" Dimension design will attempt to find a distance that will minimize "A" while keeping the girder from impinging into the slab at the highest camber location.

If "A" dimension design is disabled, the program will use the current project value.

Lifting Design

The lifting design algorithm will attempt to optimize values of lifting loop location, concrete strength, number of harped strands, and number of temporary strands so the girder can be safely lifted in the casting yard.

Hauling Design

The hauling design algorithm will attempt to optimize values of support locations, concrete strength, and number of temporary strands so the girder can be safely trucked from the casting yard to the construction site.

Strand Slope Design

Limiting max strand slope is a manufacturability requirement. If enabled, the algorithm will check to make sure the slope of harped strands is below the limit and will attempt to lower the harped pattern at the girder ends if it is.

Note that this option is only applicable to harped girder design.

Hold Down Force Design

Limiting max hold down force is a manufacturability requirement. If enabled, the algorithm will check to make sure the hold down force is below the limit and will lower the harped pattern at the girder ends if it is.

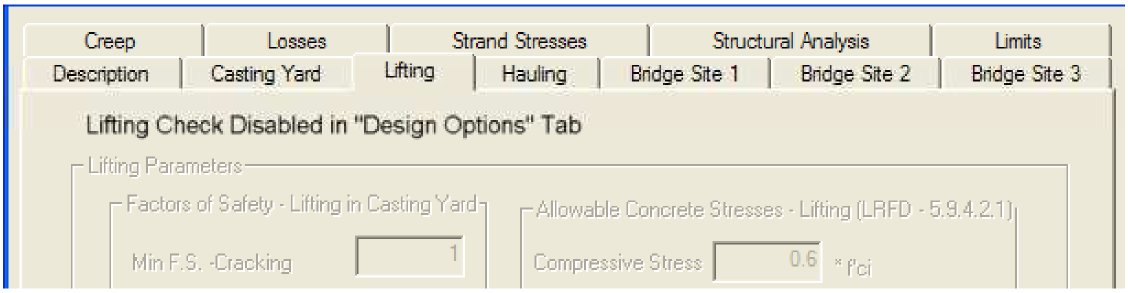
Note that this option is only applicable to harped girder design.

Fill Order for Harped and Straight Strand Design

This option tells the designer to either fill strands using the global strand order defined in the girder library entry, or to use a target proportion of straight to harped strands.

Changes to Other Design Criteria Tabs

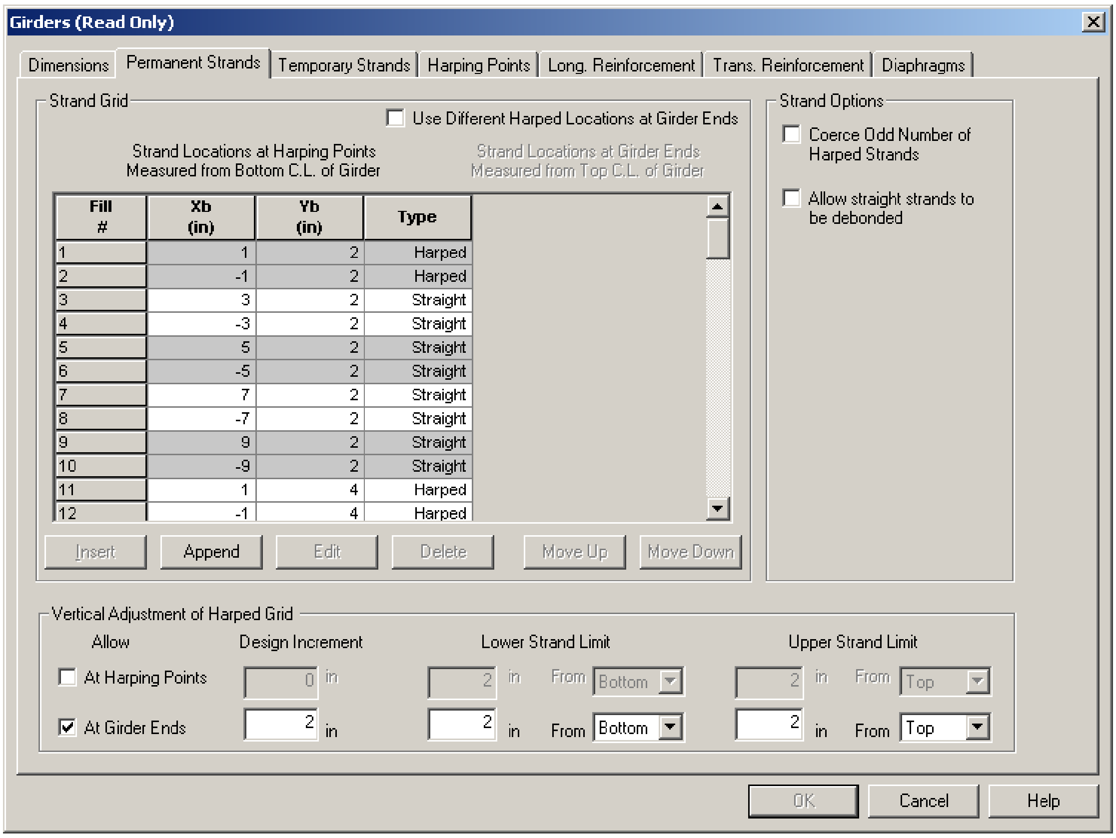
Additional changes must also be made to the "Lifting", "Hauling", and "Casting Yard" tabs. When a criterion Check is disabled, all parameters will be disabled and, an informational message will be displayed to tell the user that the pertinent option has been turned off in the Design Options tab. As an example, the Lifting tab is shown below:



Other criterion will be treated similarly in their respective locations.

Girder Library Entry Dialog

The "Permanent Strands" tab in the Girder entry dialog shown below contains several parameters that directly affect the design algorithm. Note that changes required for Debond Design are defined in Appendix B.



Strand Fill Order

The design algorithm fills strands using the strand order(s) defined on this tab. Straight and harped strands are filled independently if “Select Number of Strands Using Number of Harped and Number of Straight” is selected in the Girder Editor dialog (discussed later).

Strand Pattern Design

If harped strands exist, PGSuper will execute a harped pattern design. If only straight strands exist and “Allow straight strands to be debonded” is selected, a debond design will be done, otherwise a straight strands only design will be done.

Vertical Adjustment of Harped Strands

If harped strands exist, vertical adjustment of harped strand grids at the girder ends or harping points can be allowed, and the range of adjustment can be specified.

The design algorithm uses the design increment to vertically adjust strands. If the design increment is zero, the algorithm will not adjust the strands. However, users can manually adjust the strands in the Girder Editing dialog.

Questions/Open Issues

- Flowcharts for Lifting and Hauling are high-level and do not reflect all details in the implementation.

Description of the Appendices

The design algorithm flowcharts are in the following Appendices:

Appendix A – Flexural Design Flowcharts
The design flowcharts have been broken into four logical sections:

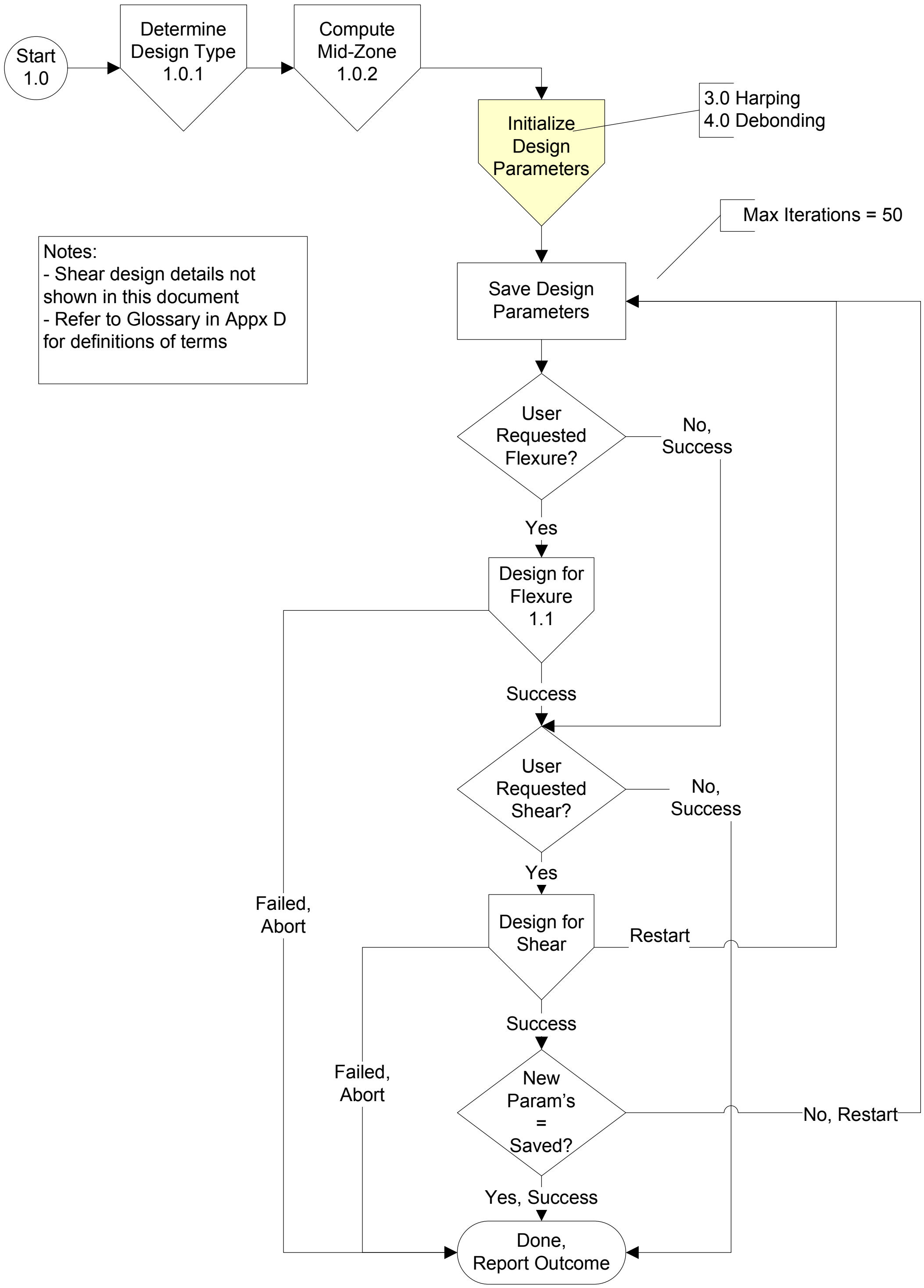
1.0 Overall driving logic of design
2.0 Common remedies to all prestressed girders
3.0 Remedies for harped design
4.0 Remidies for debond design

Appendix B – Prerequisites for Debond Design

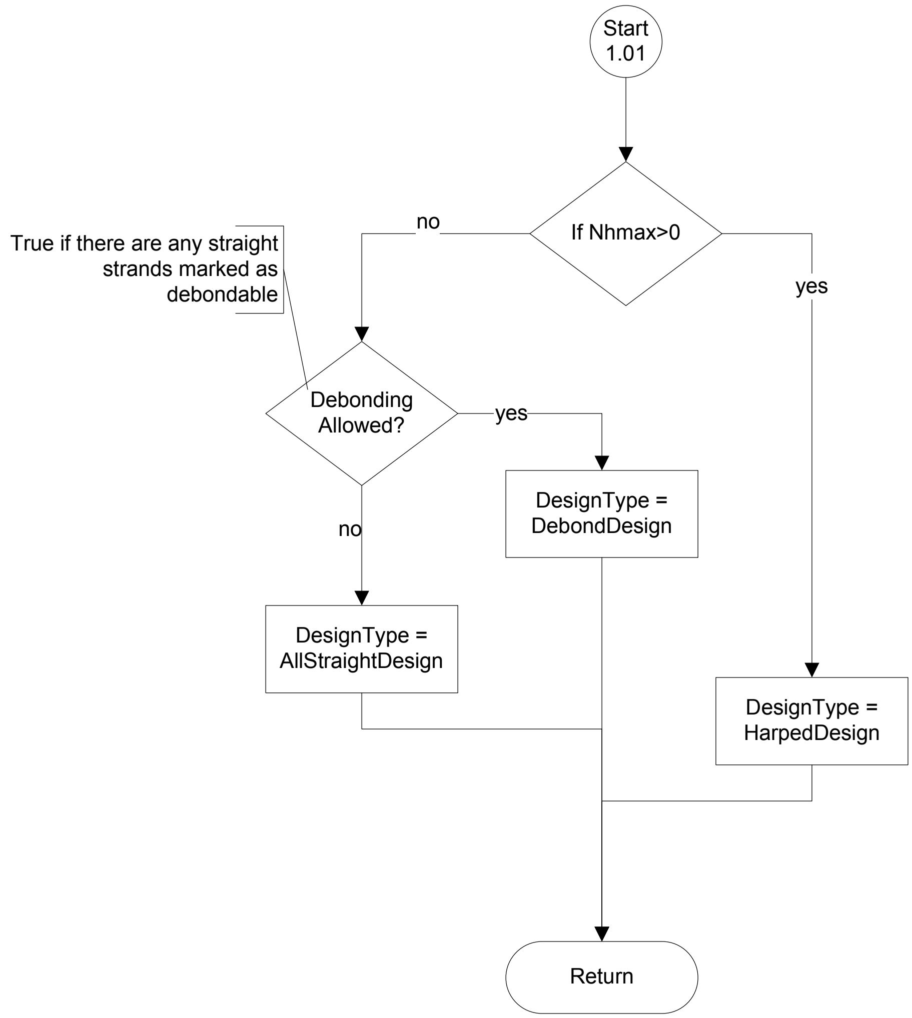
Appendix C – Glossary of Terms

Appendix A – Main Flexural Design Flowcharts

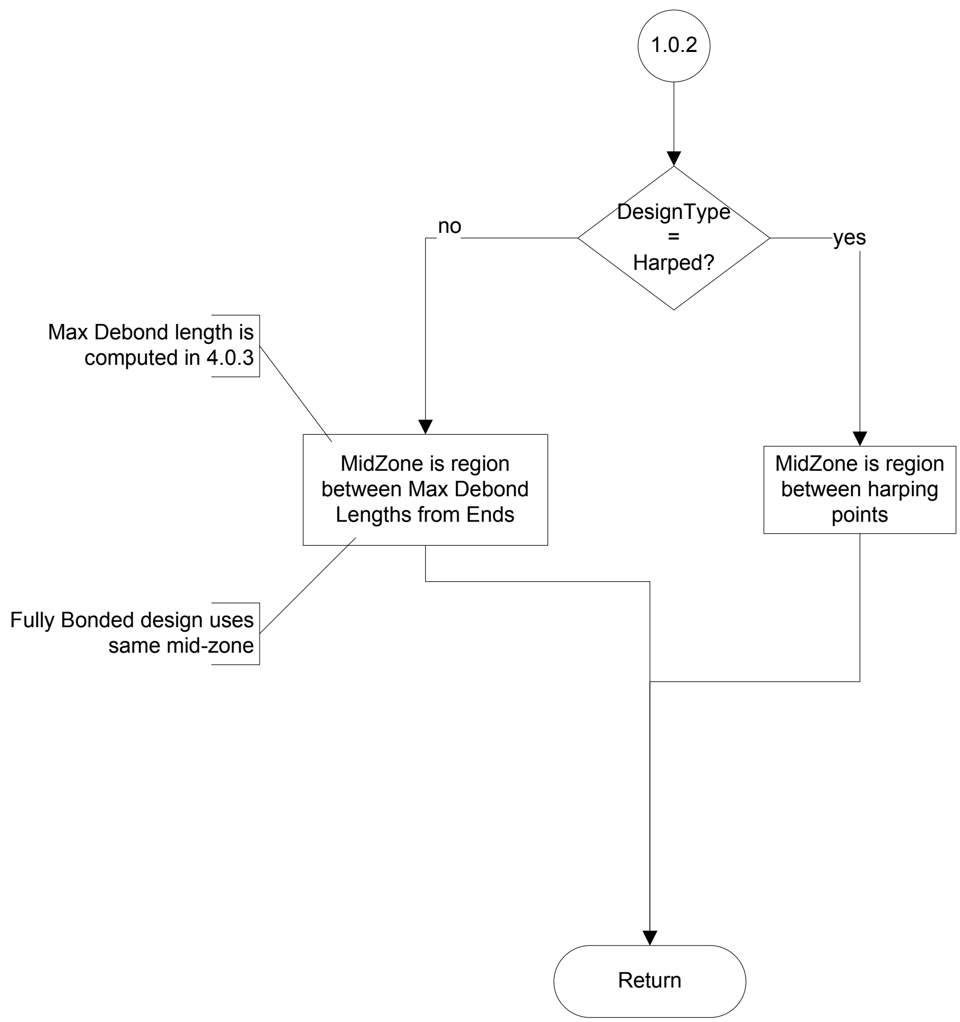
1.0 High Level Design Algorithm



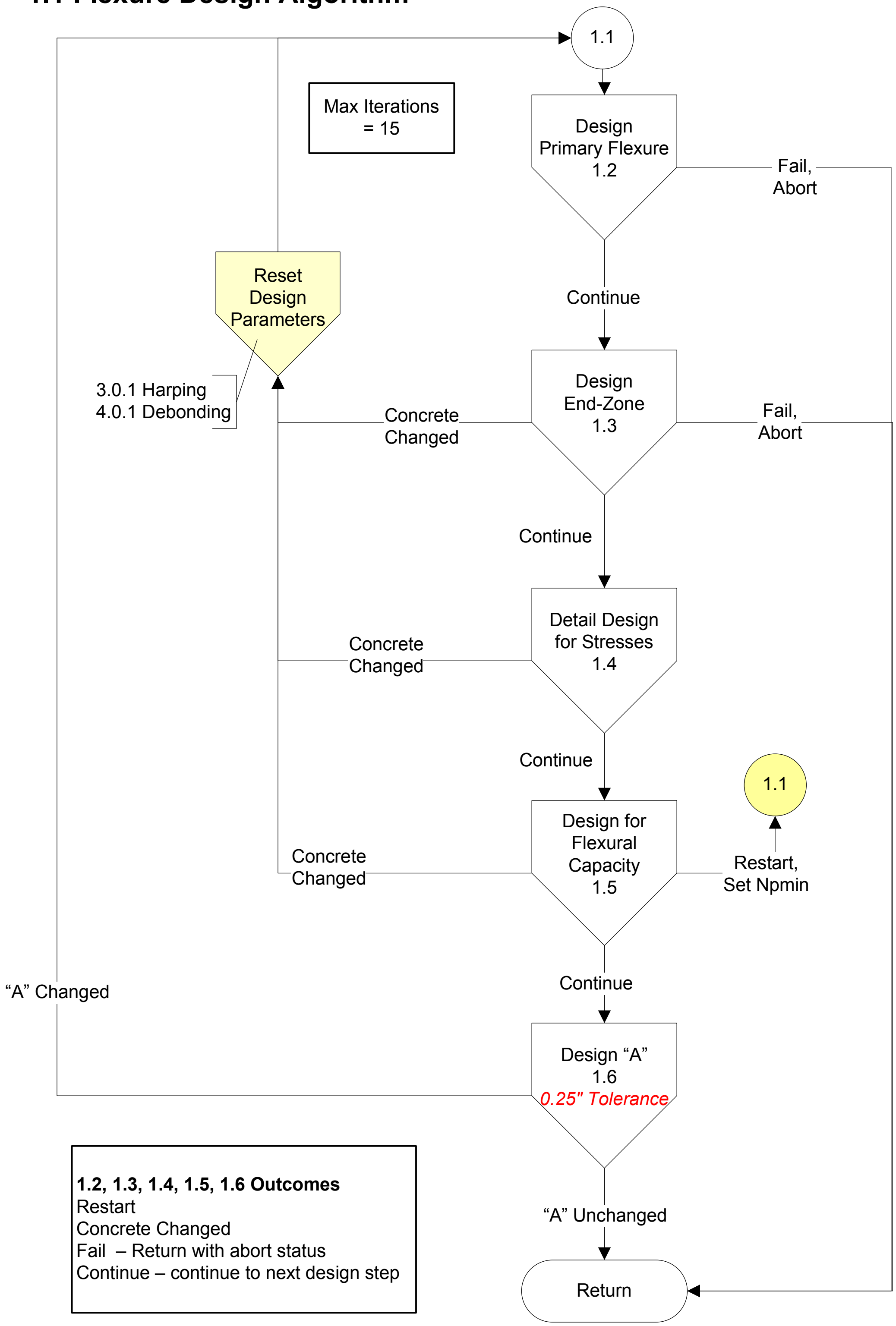
1.0.1 Determine Design Type



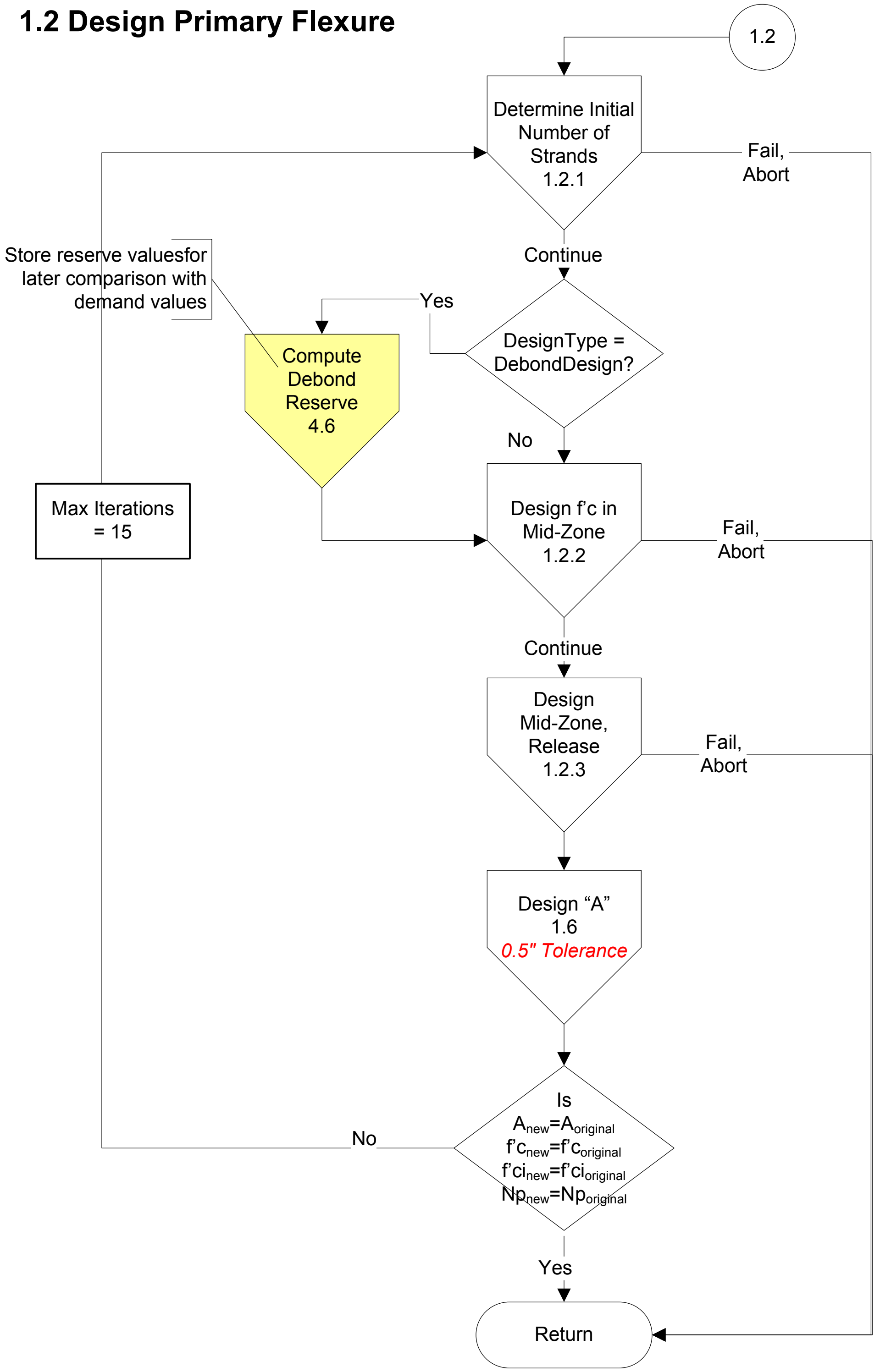
1.0.2 Compute Mid-Zone



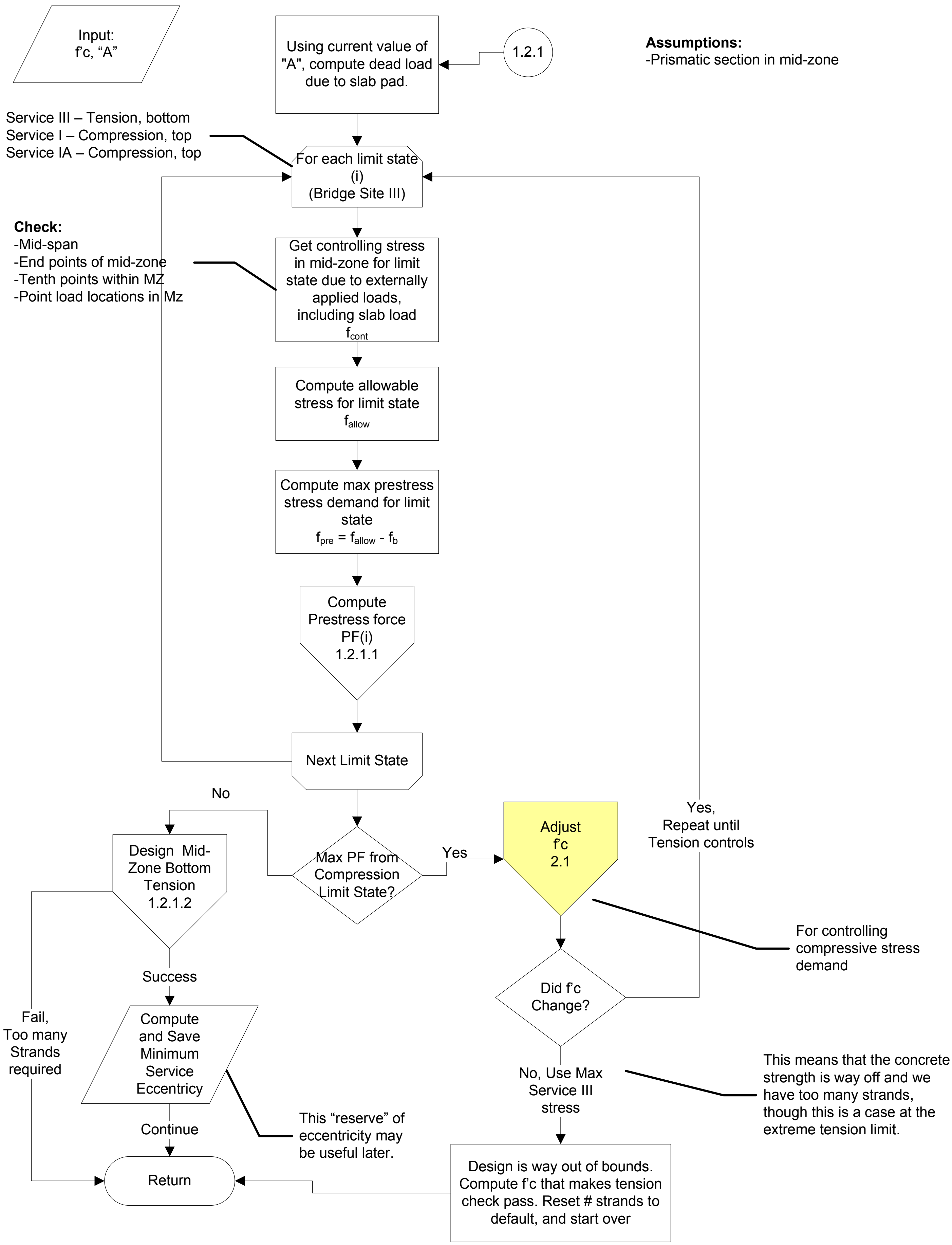
1.1 Flexure Design Algorithm



1.2 Design Primary Flexure

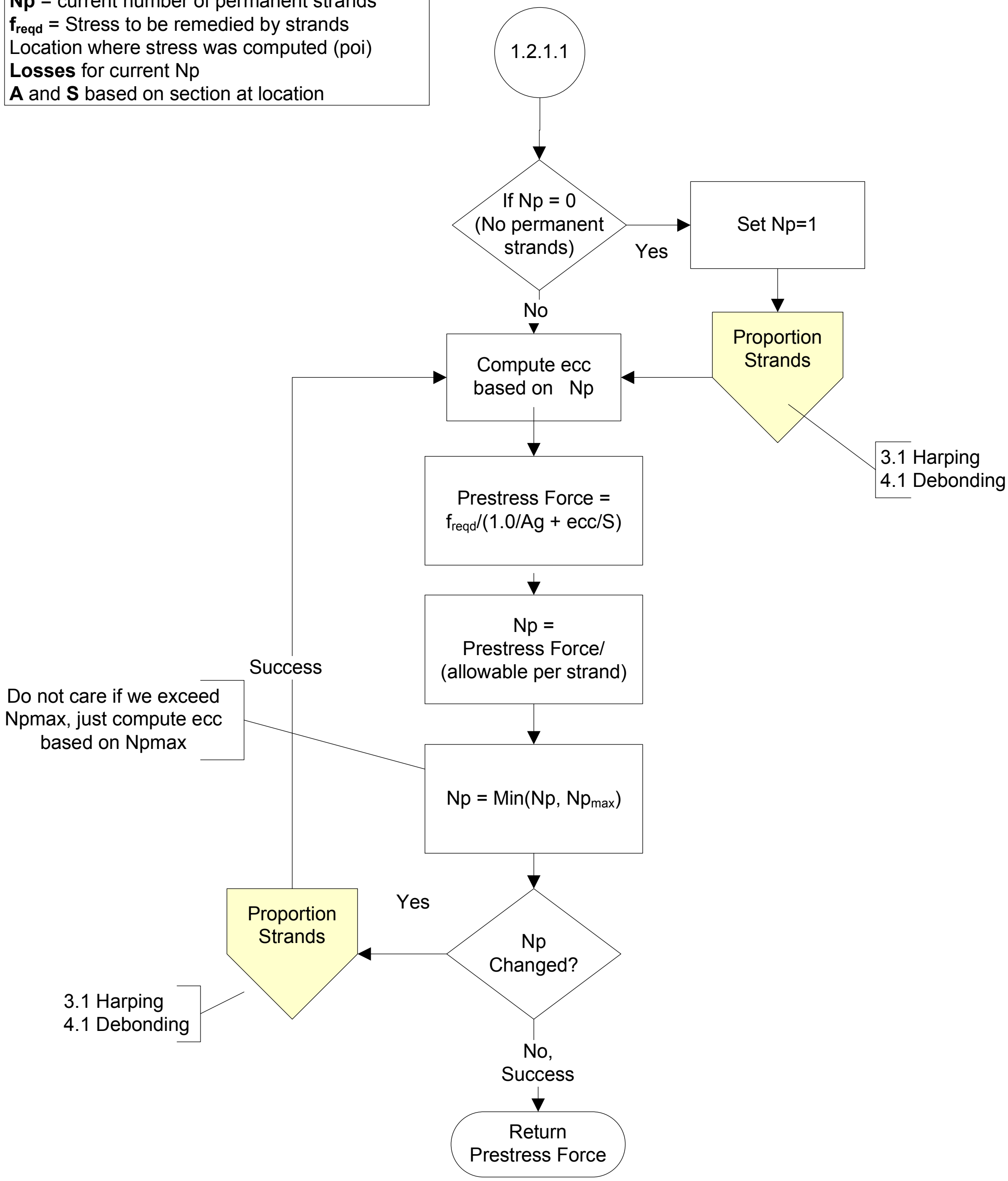


1.2.1 Determine Initial Number Of Strands – Service / MidZone

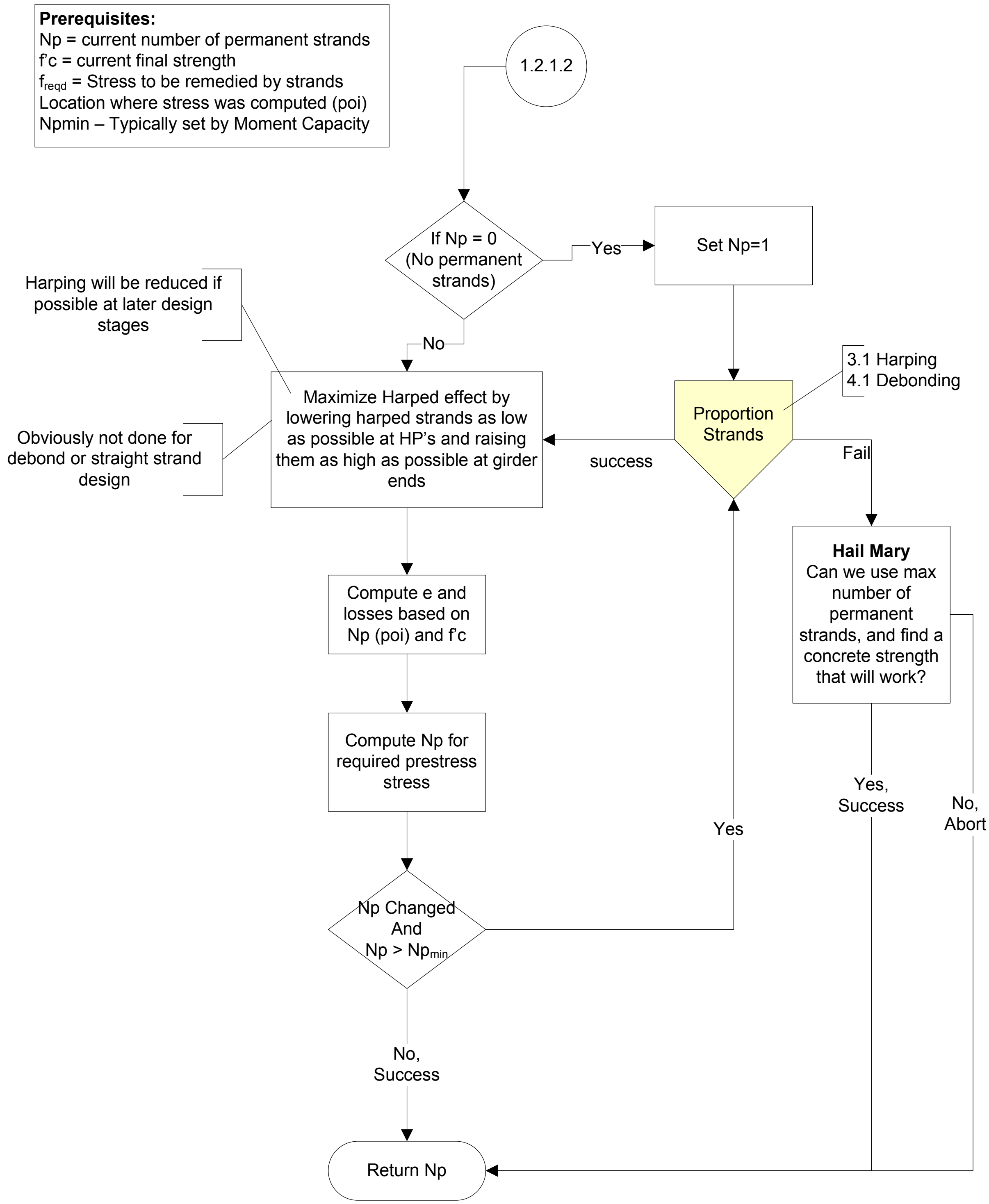


1.2.1.1 Compute Prestress Force Based on Stress Demand

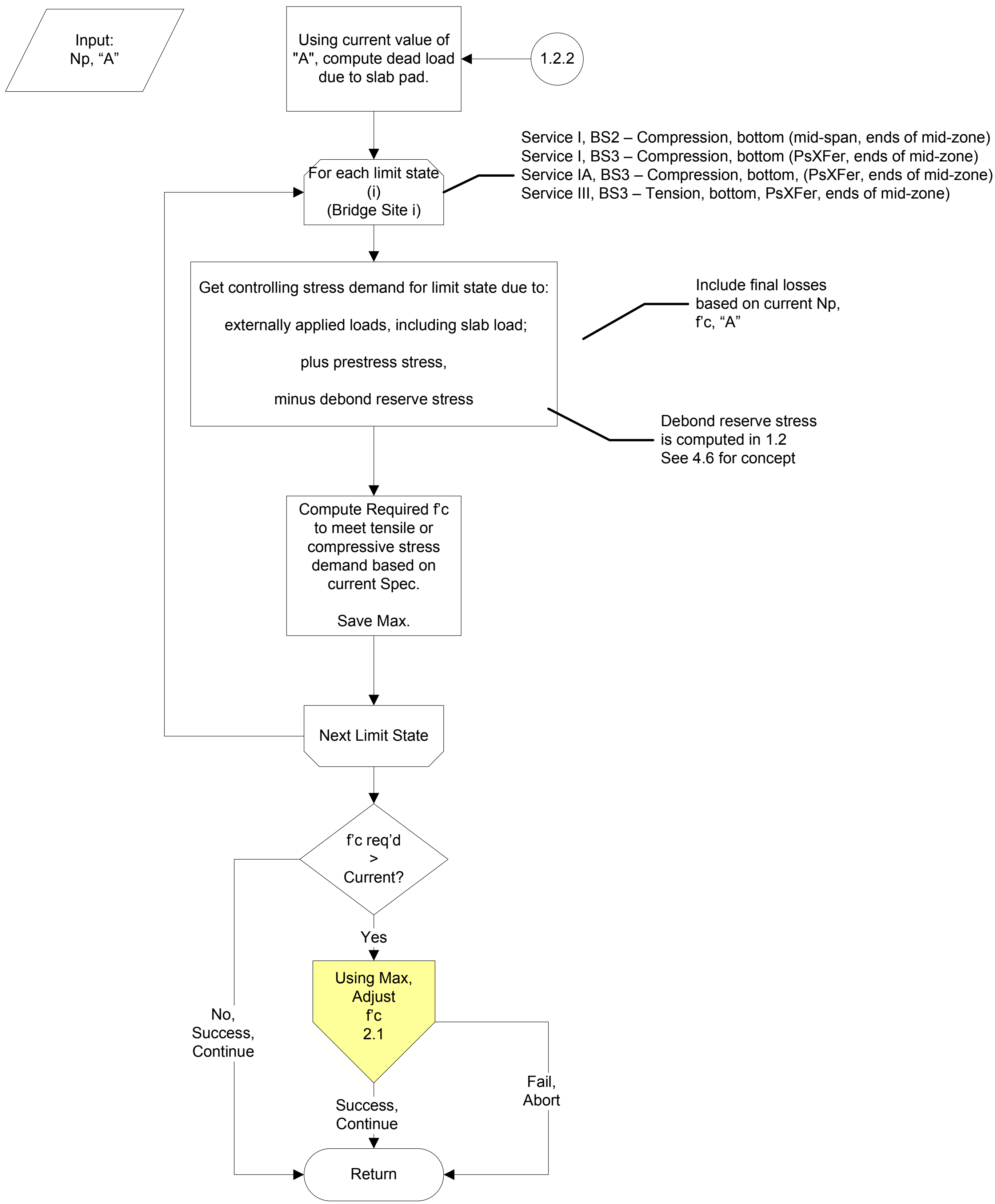
Prerequisites:
Np = current number of permanent strands
$\mathbf{f_{reqd}}$ = Stress to be remedied by strands
Location where stress was computed (poi)
Losses for current Np
A and **S** based on section at location



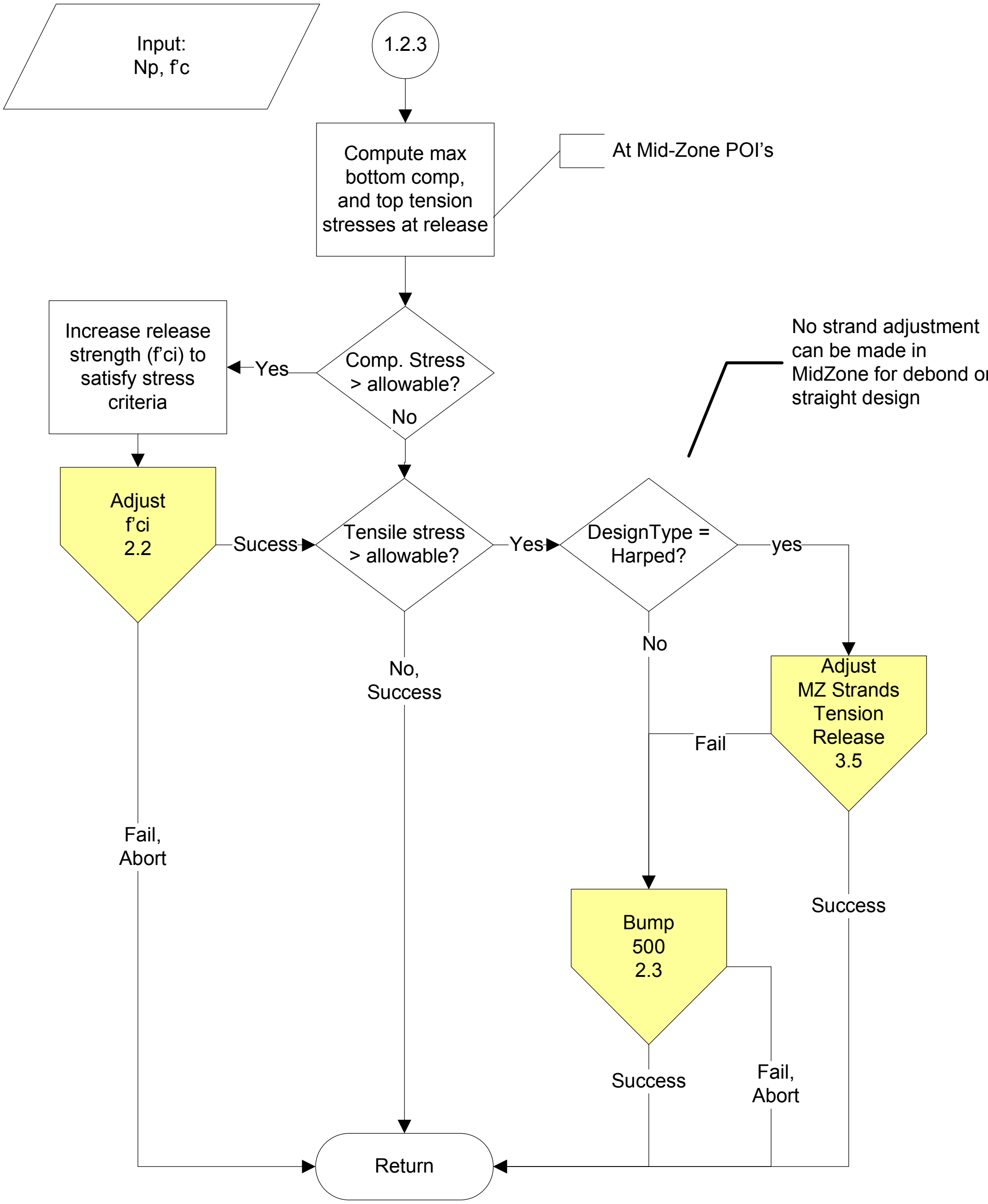
1.2.1.2 Design for Mid-Zone Bottom Tension



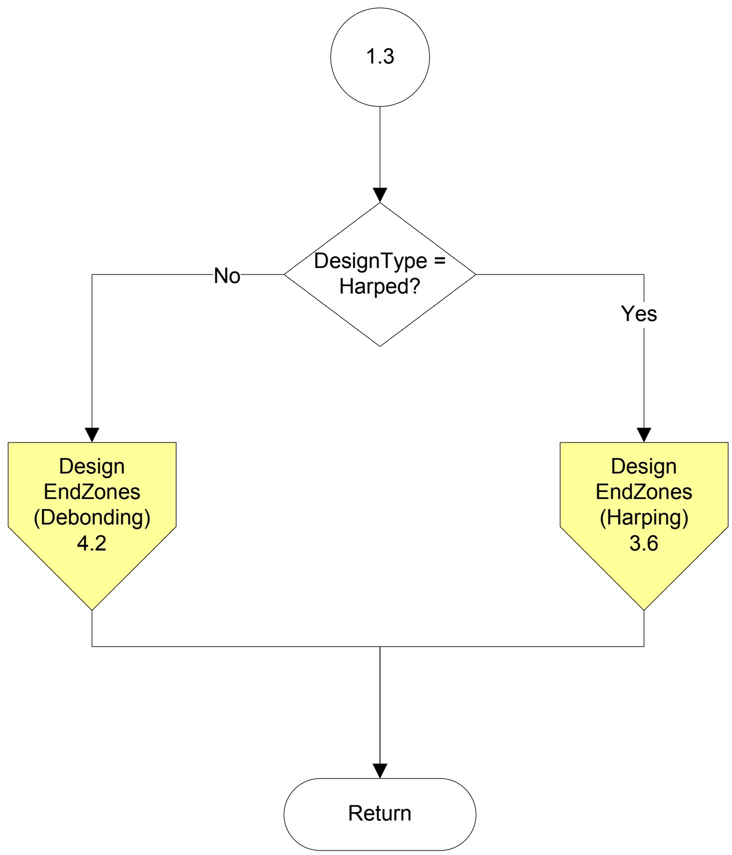
1.2.2 Determine Initial f'c



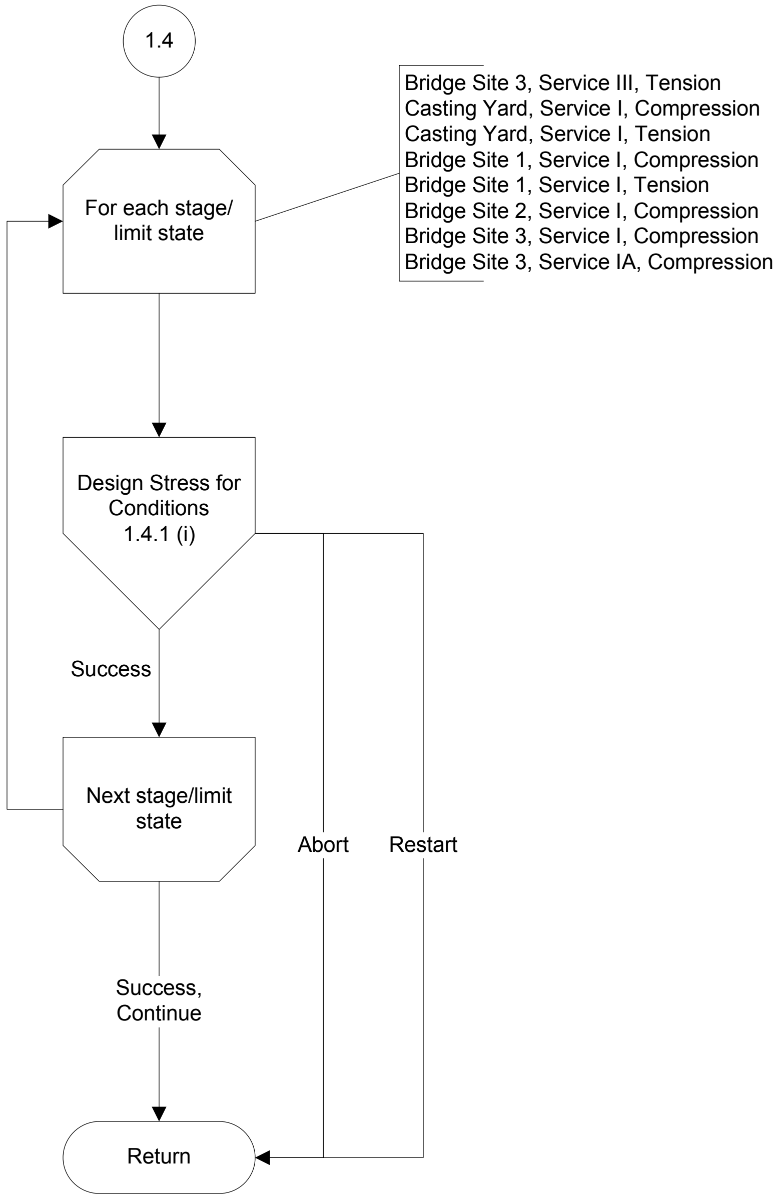
1.2.3 Design for Mid-Zone at Release



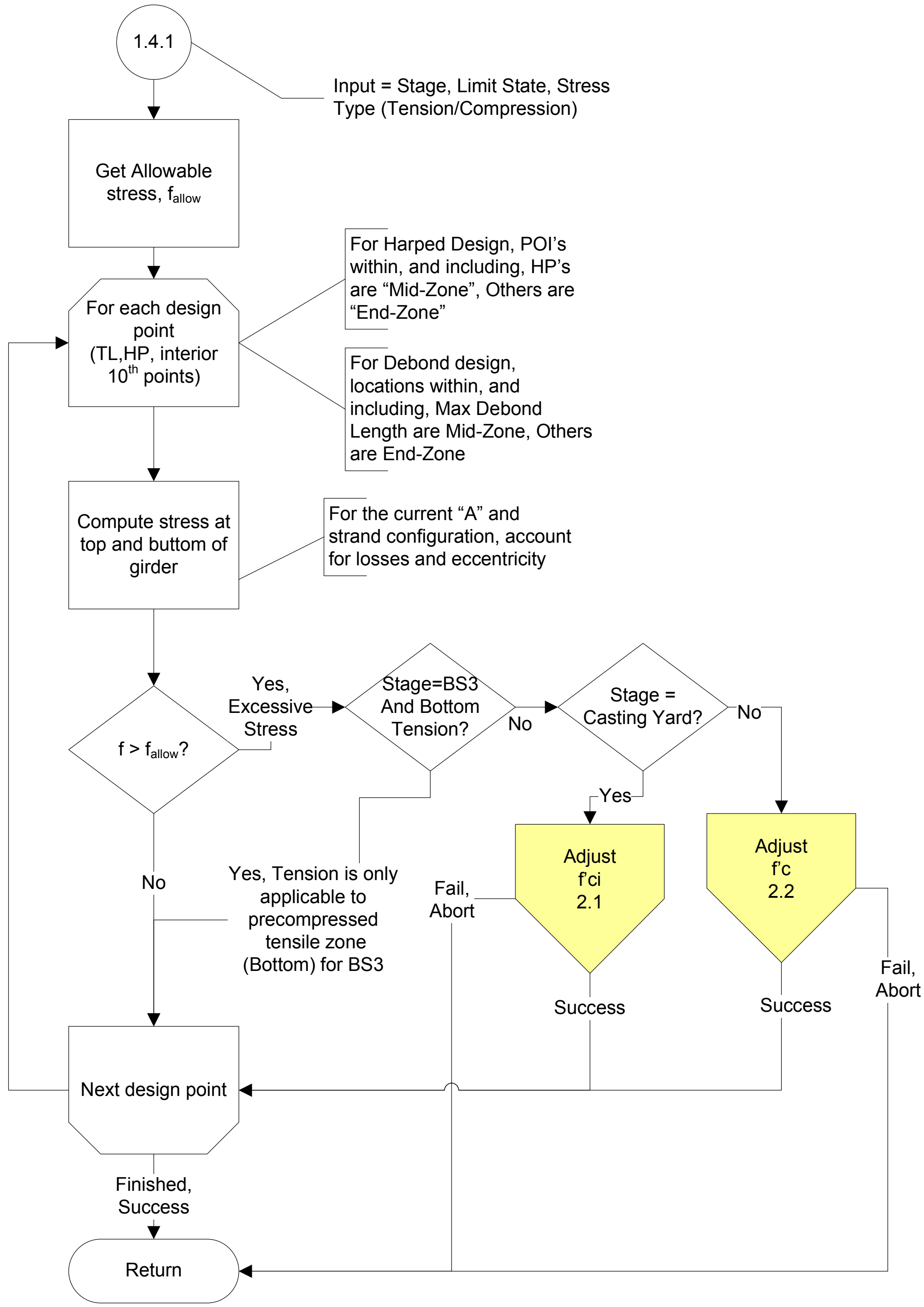
1.3 Design End Zones



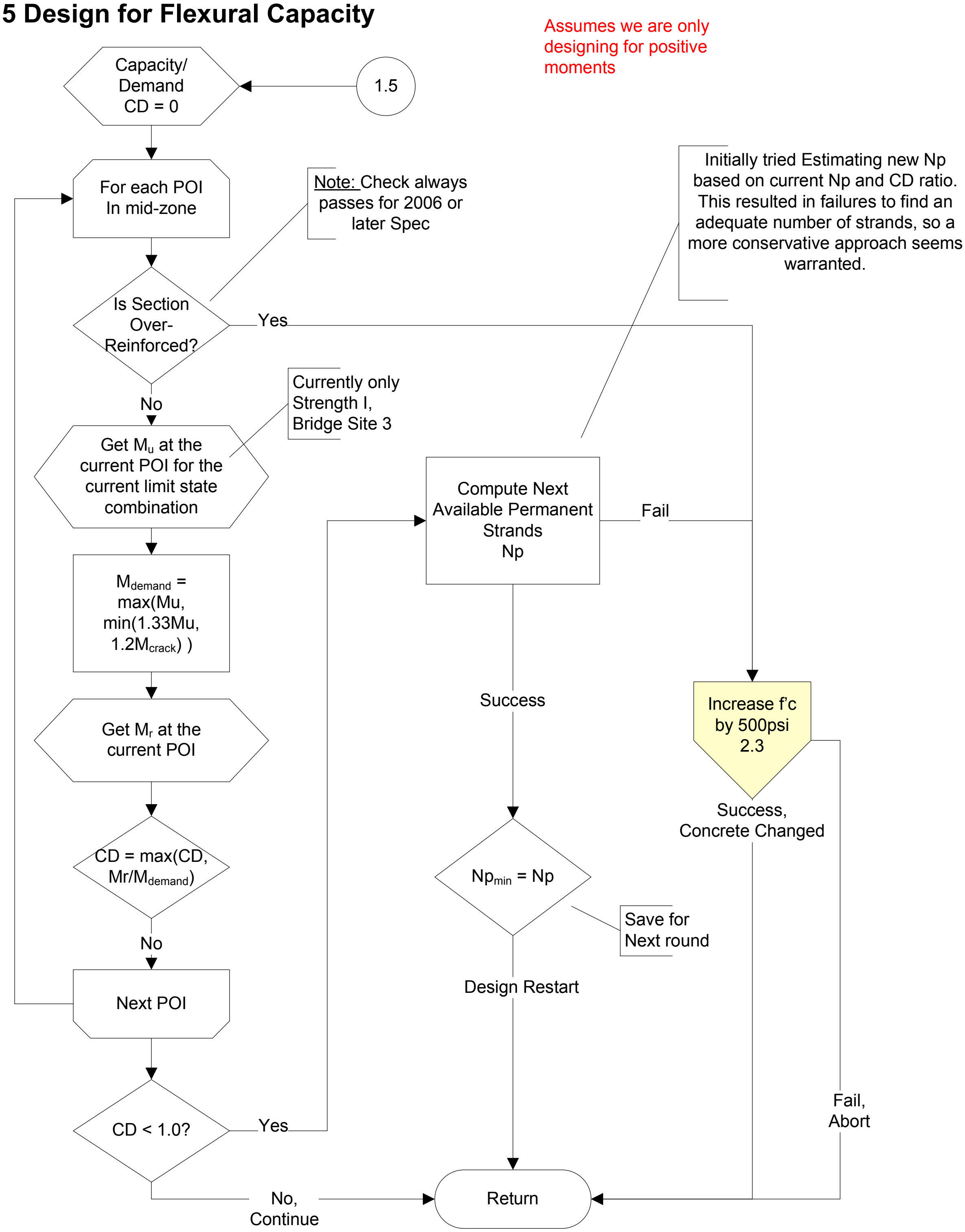
1.4 Detailed Design for Stress



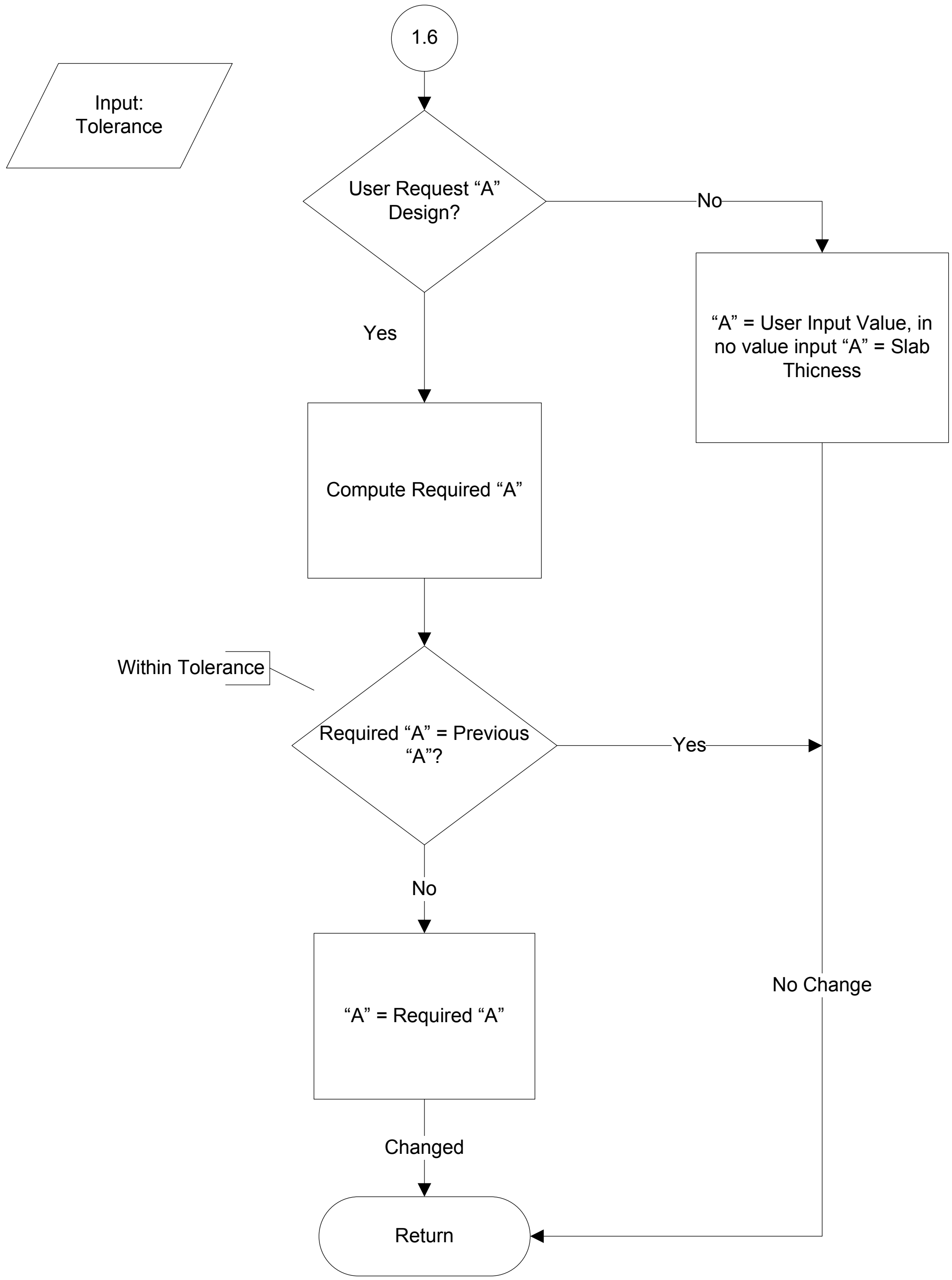
1.4.1 Design Stress For Condition



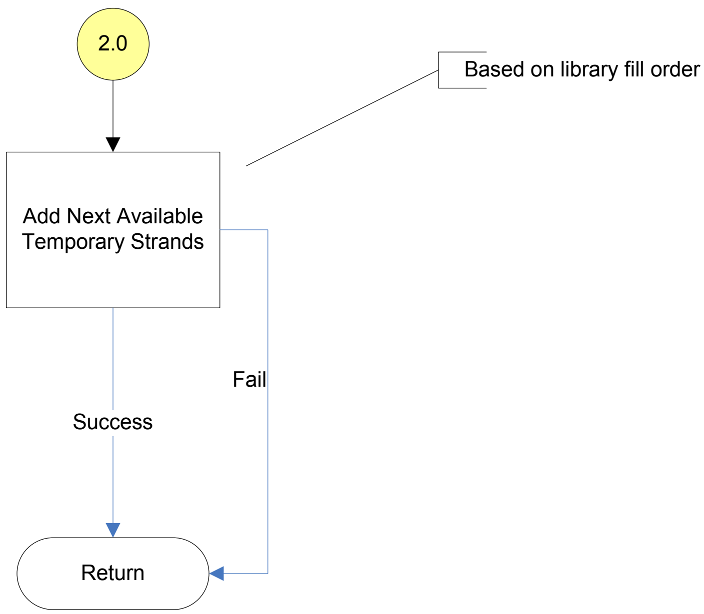
1.5 Design for Flexural Capacity



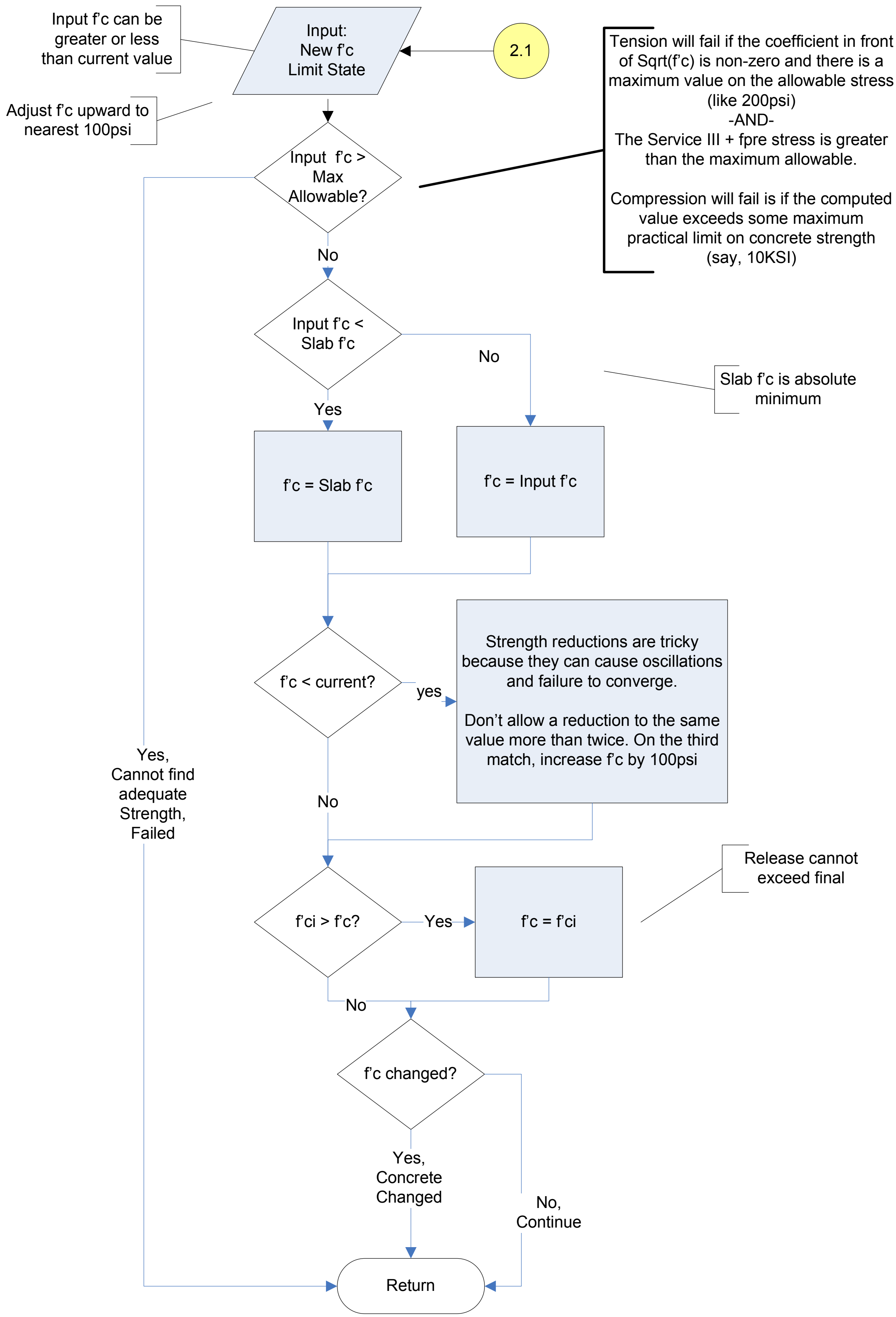
1.6 Design “A”


1.6
Input:
Tolerance
User Request “A” Design?
No
Yes
“A” = User Input Value, in no value input “A” = Slab Thicness
Compute Required “A”
Within Tolerance
Required “A” = Previous “A”?
Yes
No
“A” = Required “A”
No Change
Changed
Return

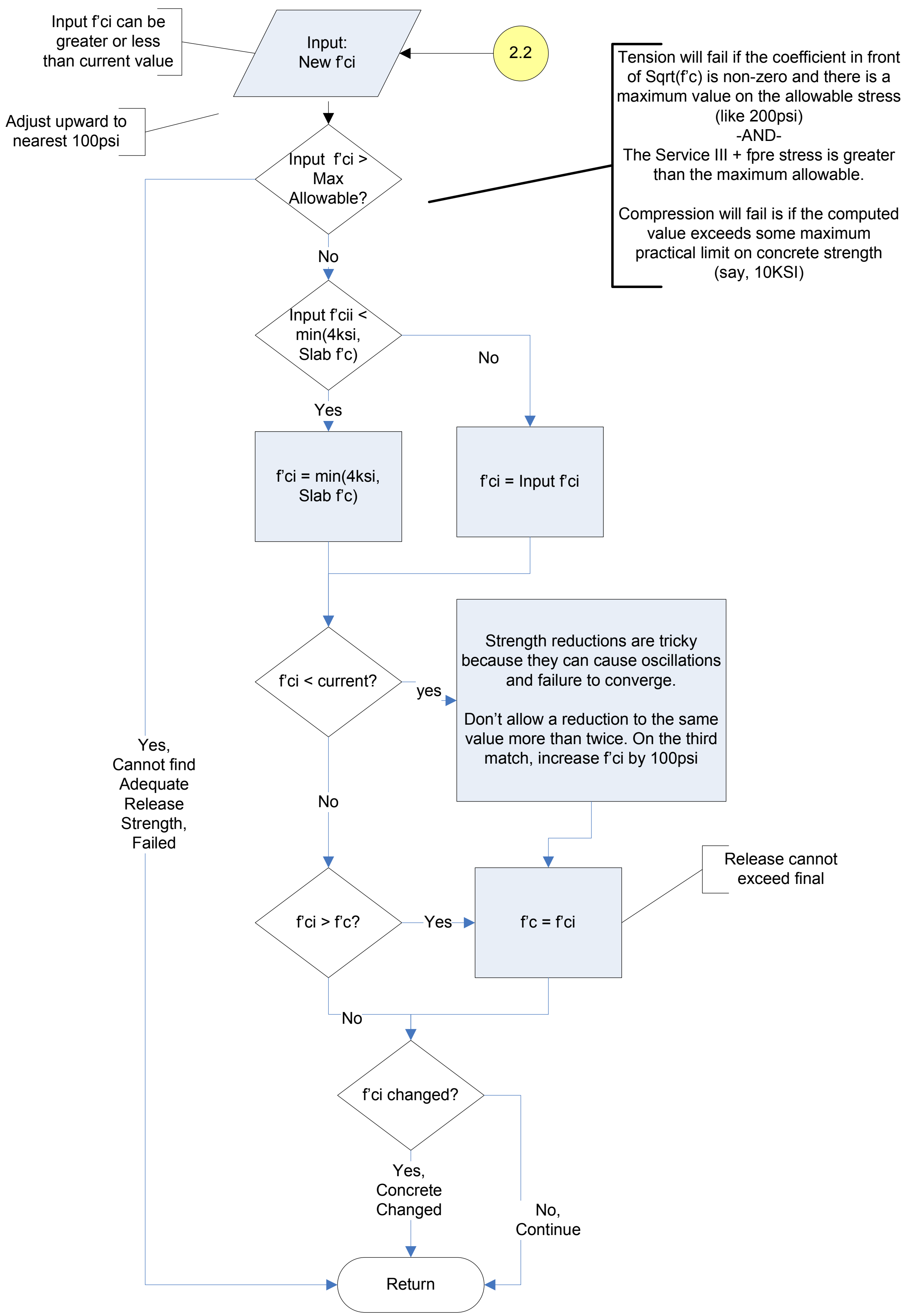
2.0 Add Temporary Strands to Girder



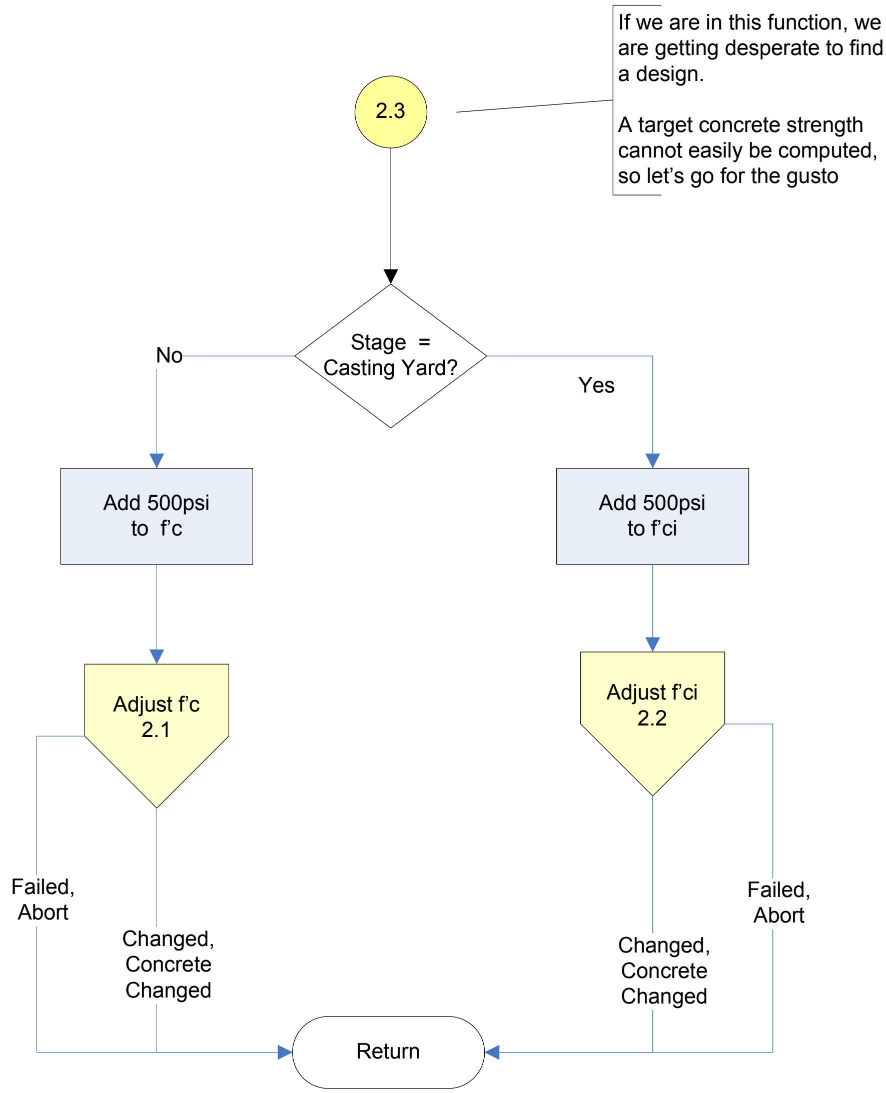
2.1 Adjust Girder Final Strength, f'c



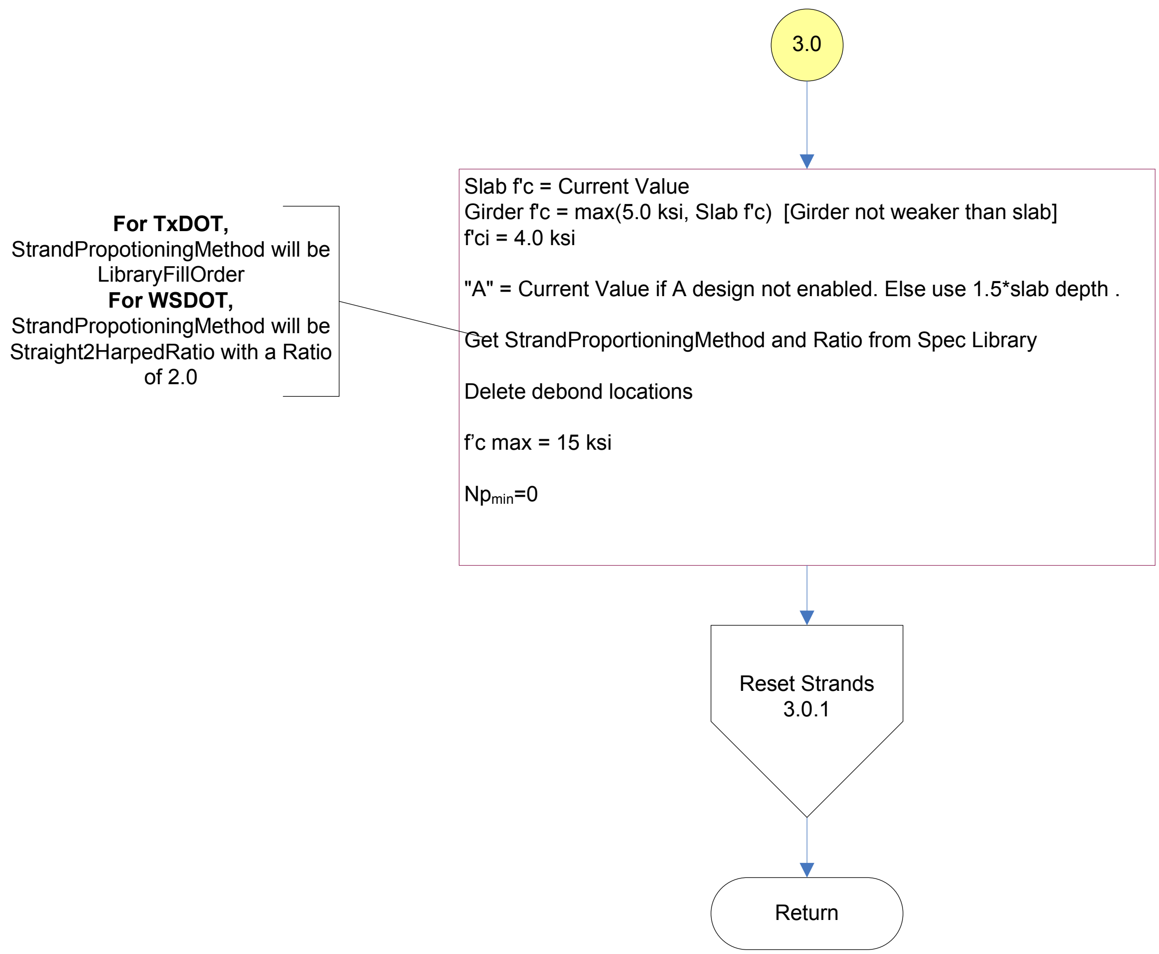
2.2 Adjust Girder Release Strength, f'ci



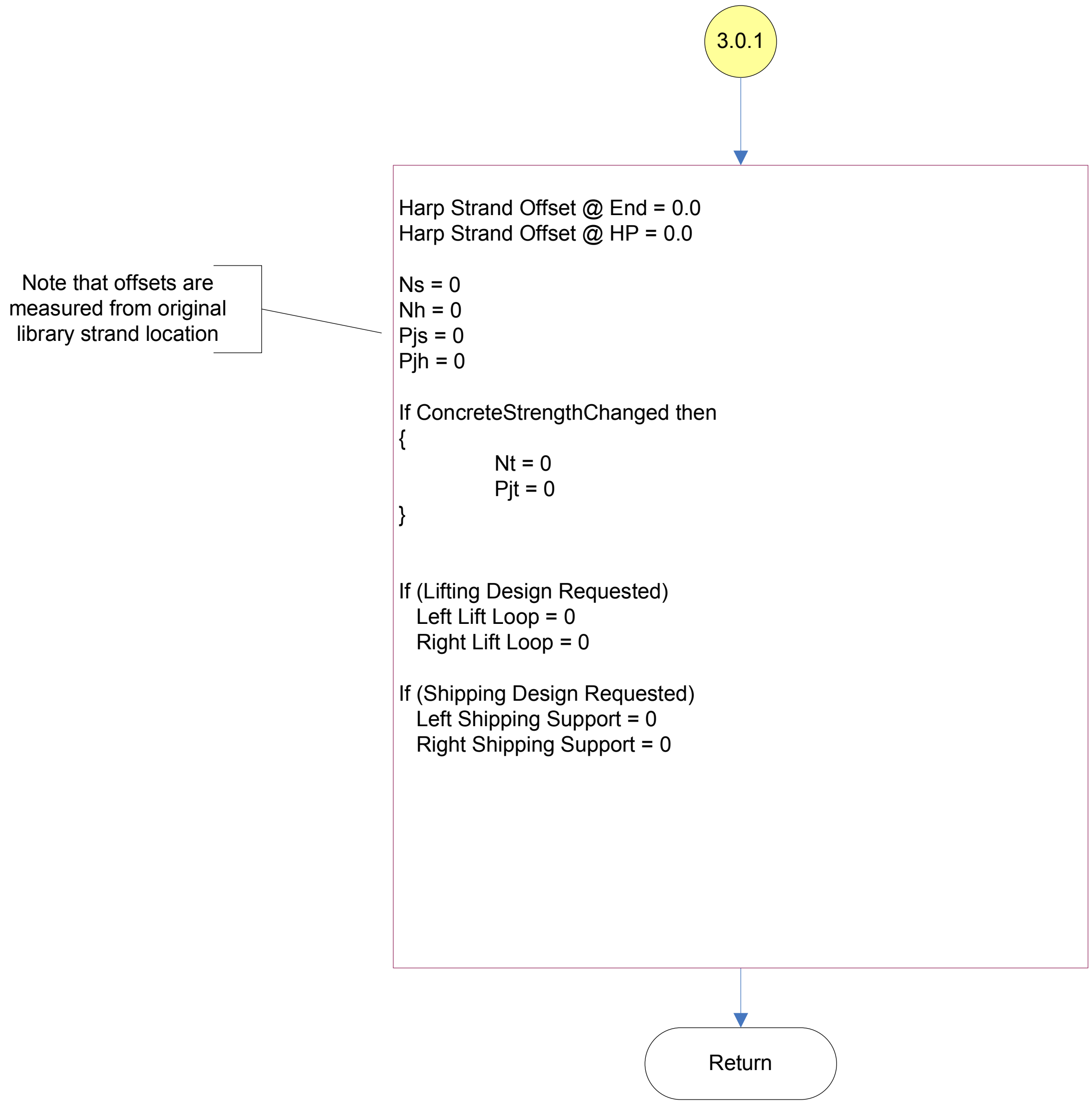
2.3 Bump 500 – Increase Concrete Strength By 500 psi



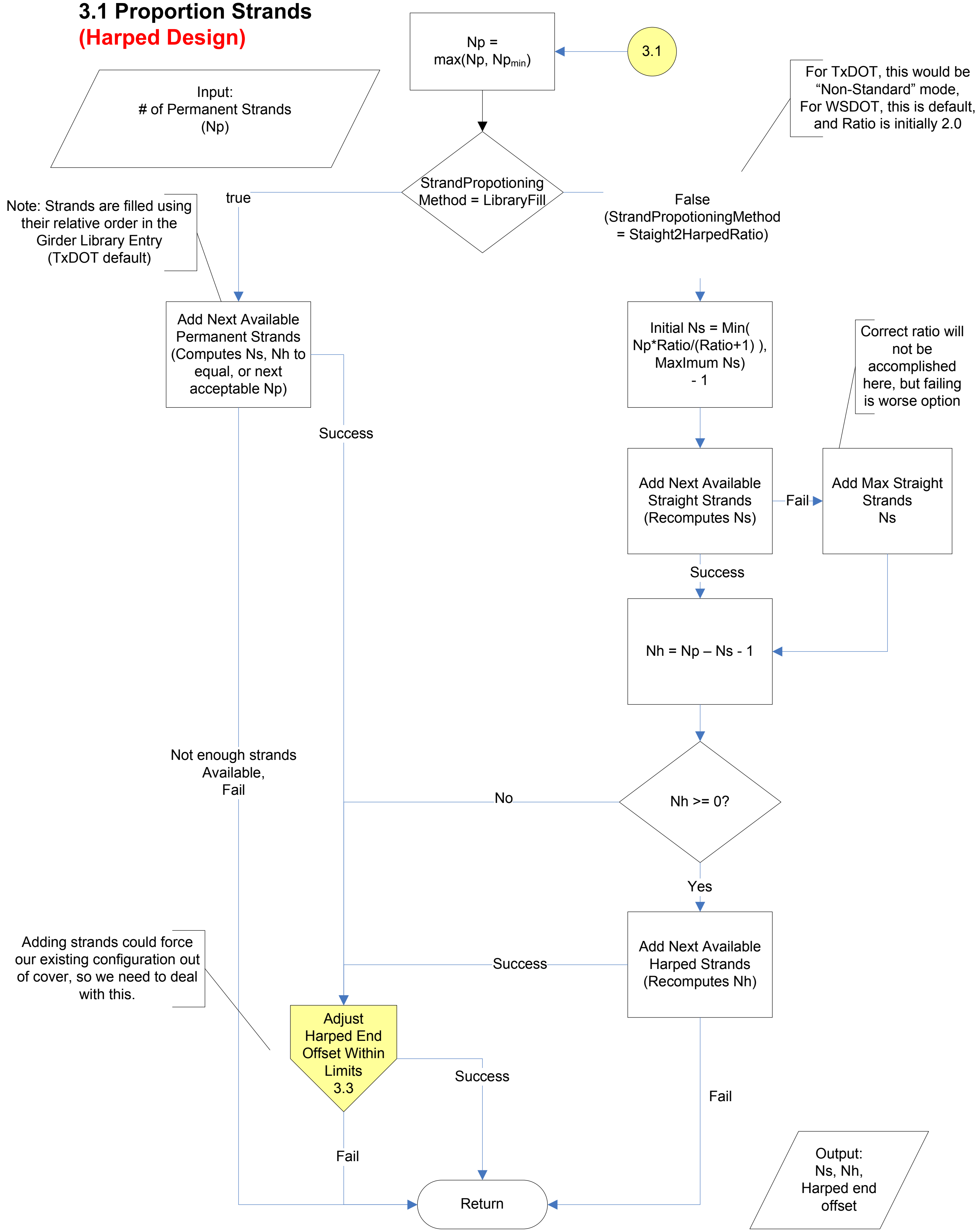
3.0 Initialize Design Parameters (Harped Design)



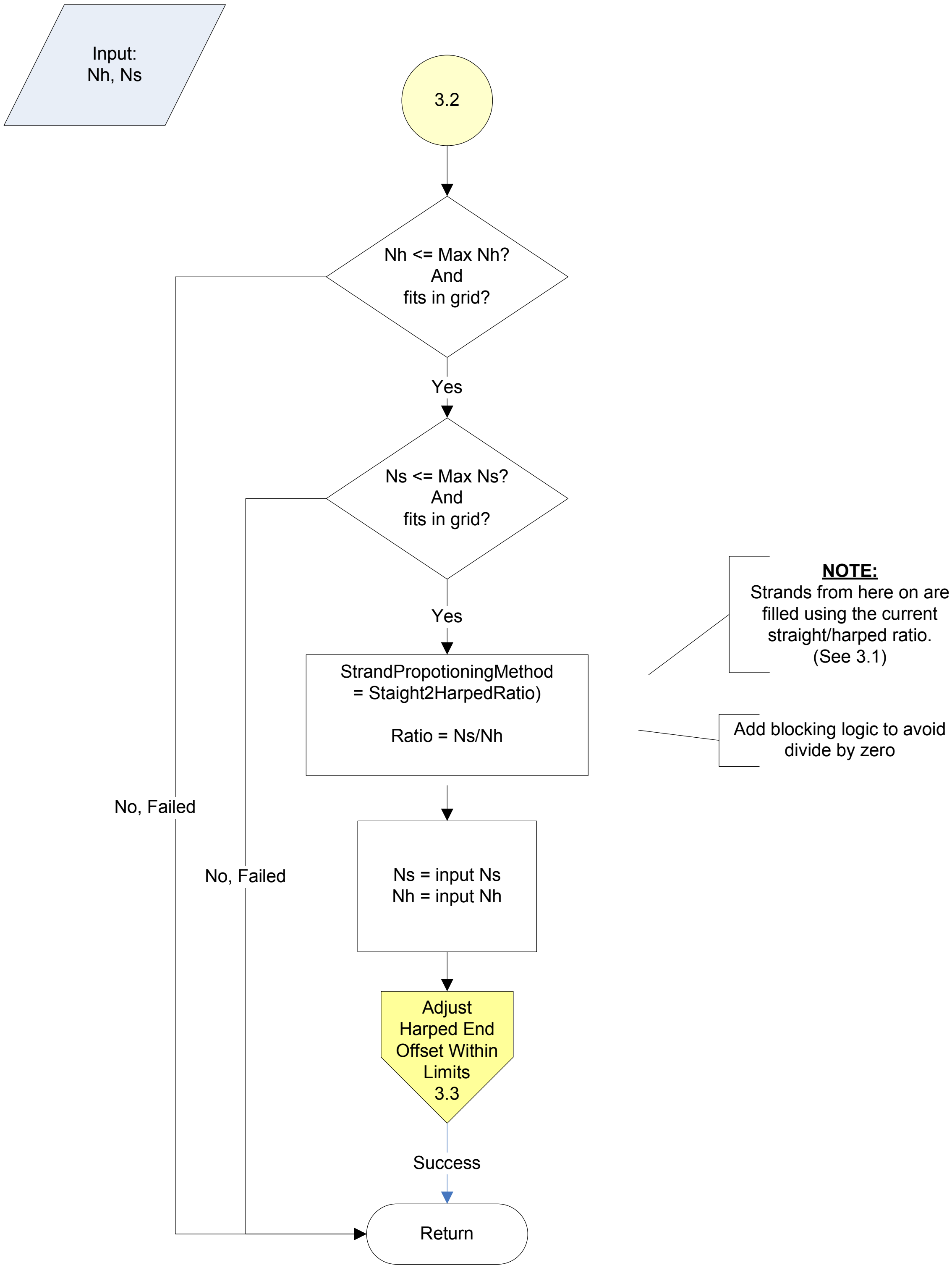
3.0.1 Reset Parameters (Harped Design)



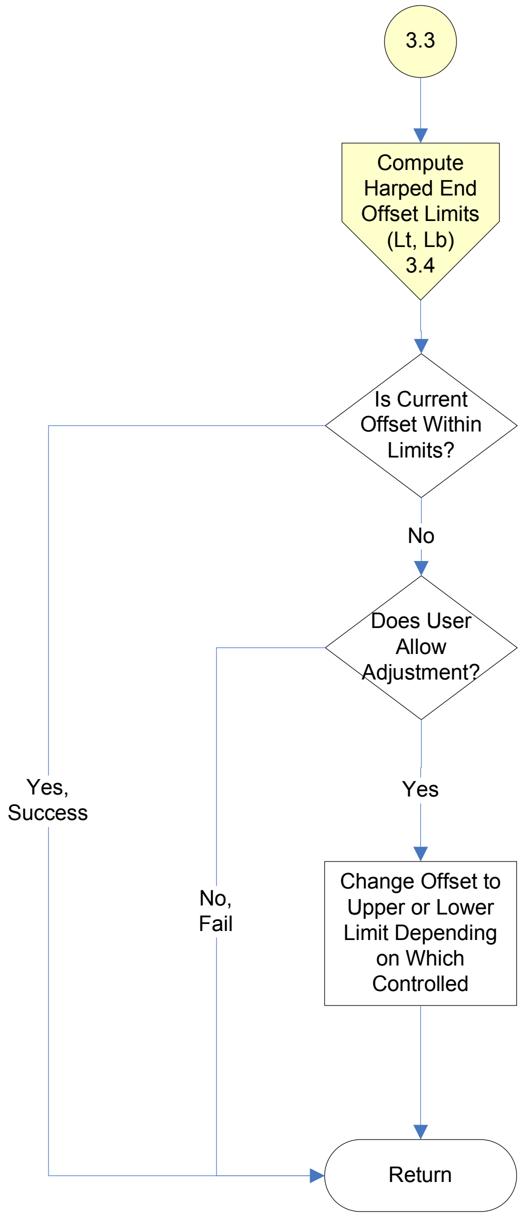
3.1 Proportion Strands
(Harped Design)



3.2 Set Number of Harped and Number of Straight Strands

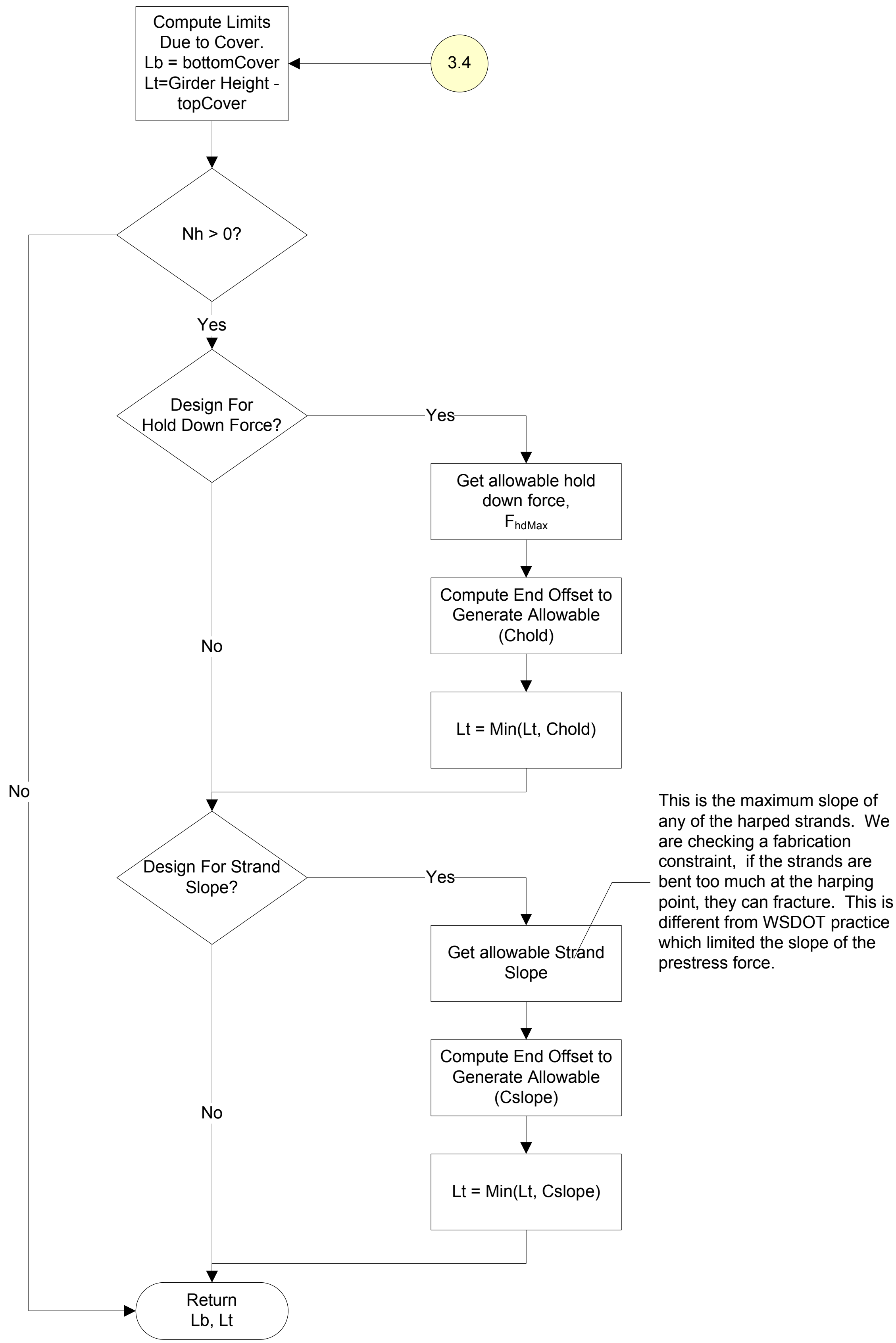


3.3 Adjust Harped End Offset Within Limits

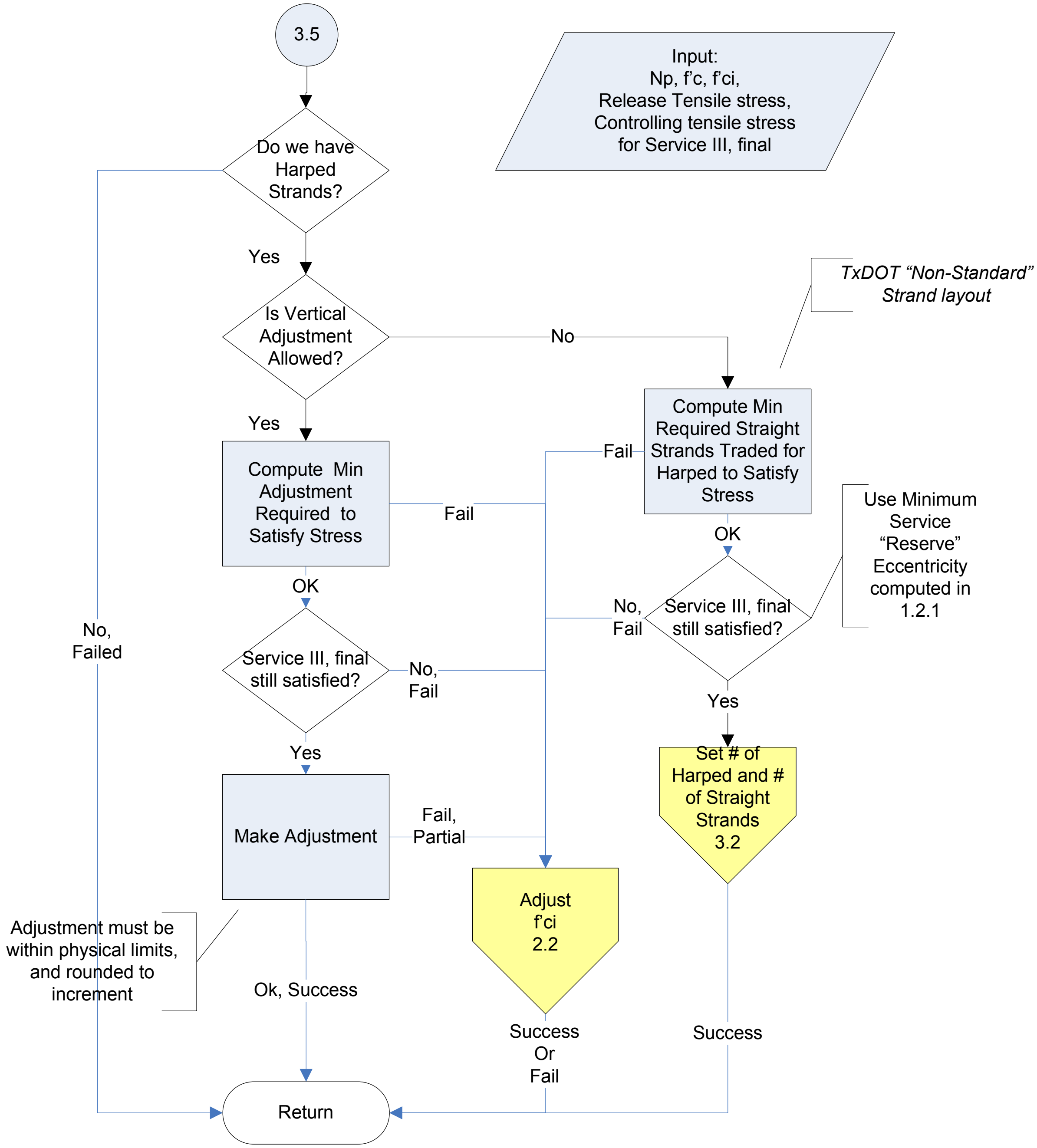


Assumes that harping is symmetric, so we don’t need to compute at both ends

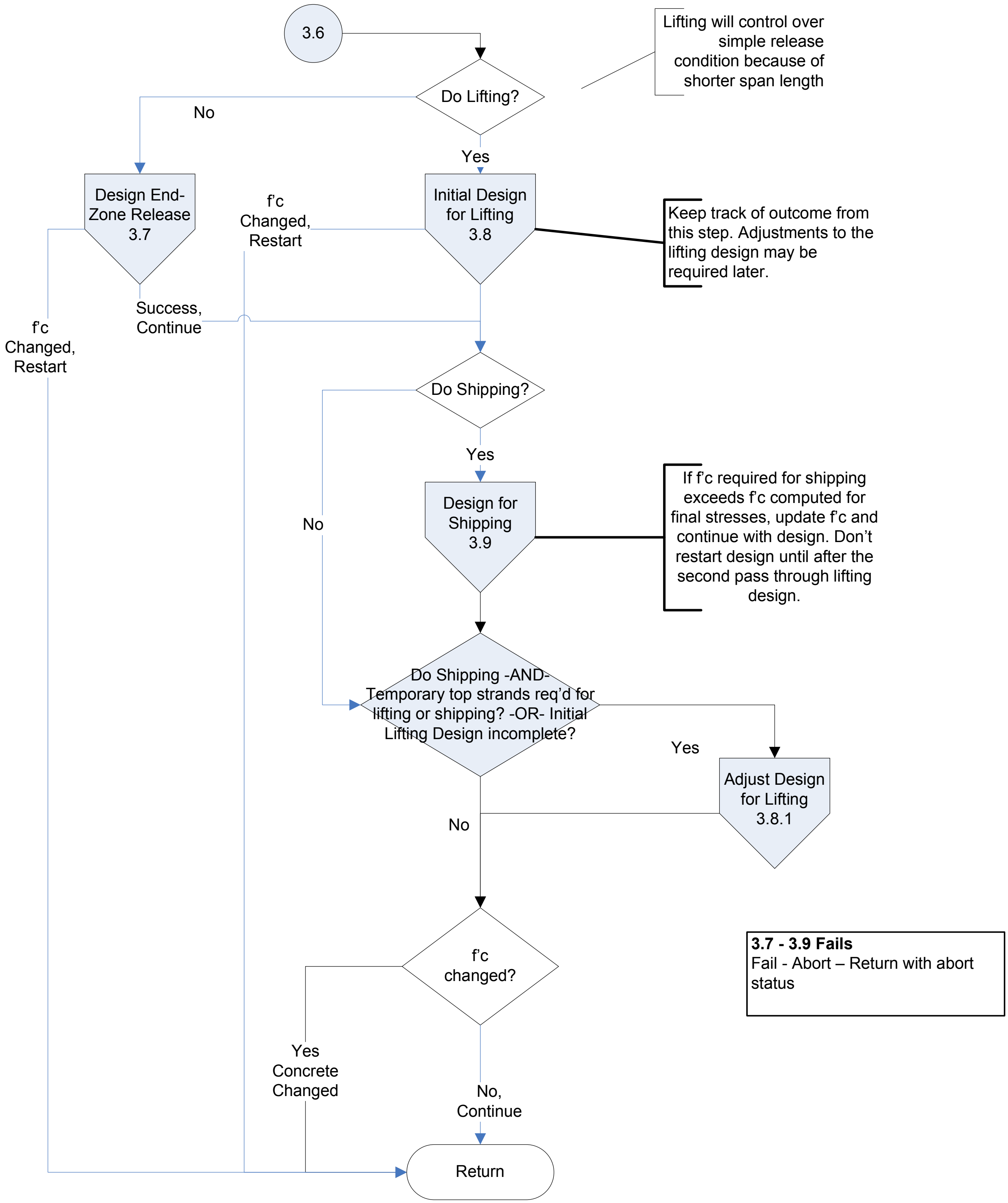
3.4 Compute Harped End Offset Limits



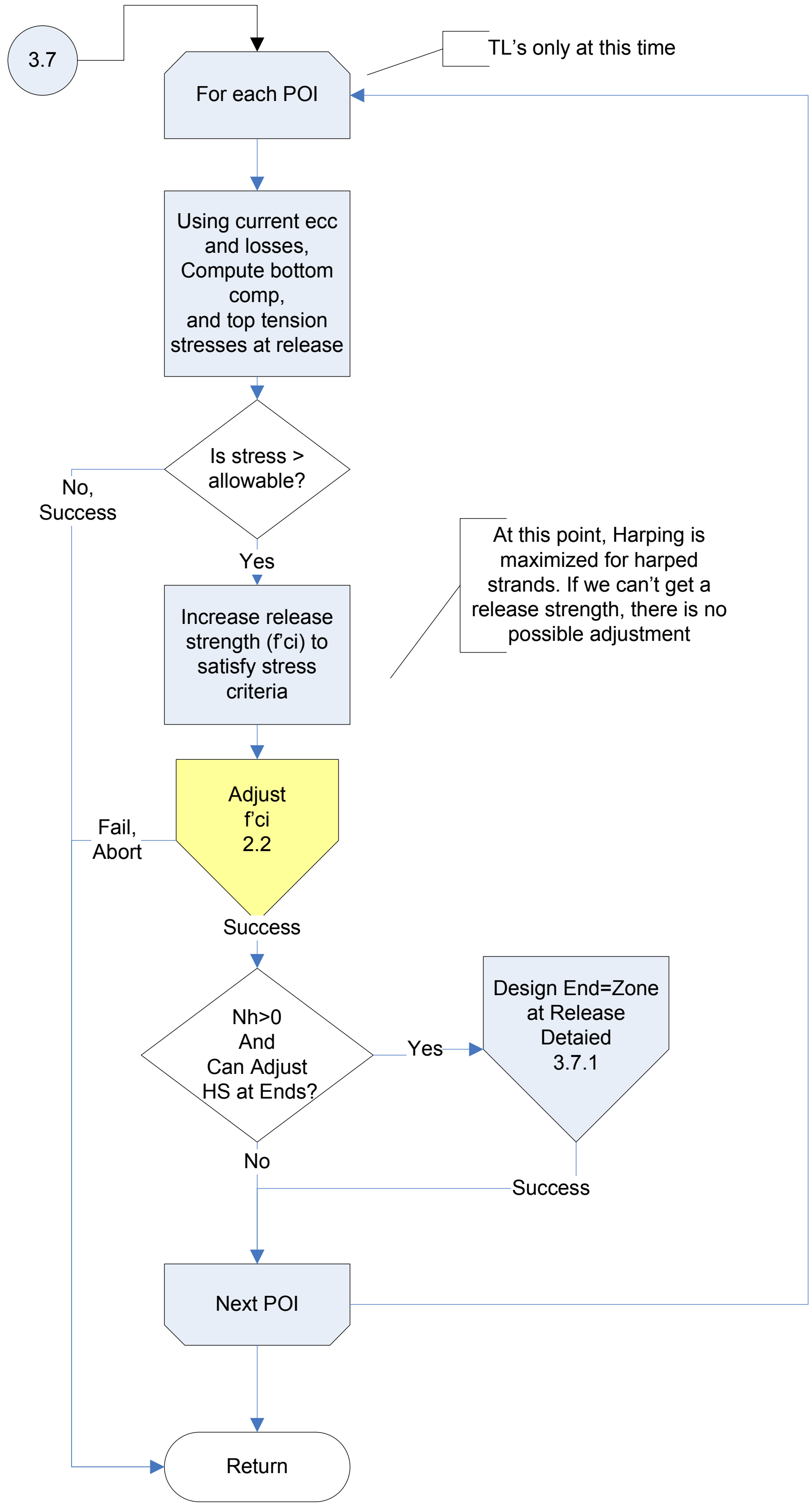
3.5 Mid-Zone Tension Adjust Harped Strands at Release



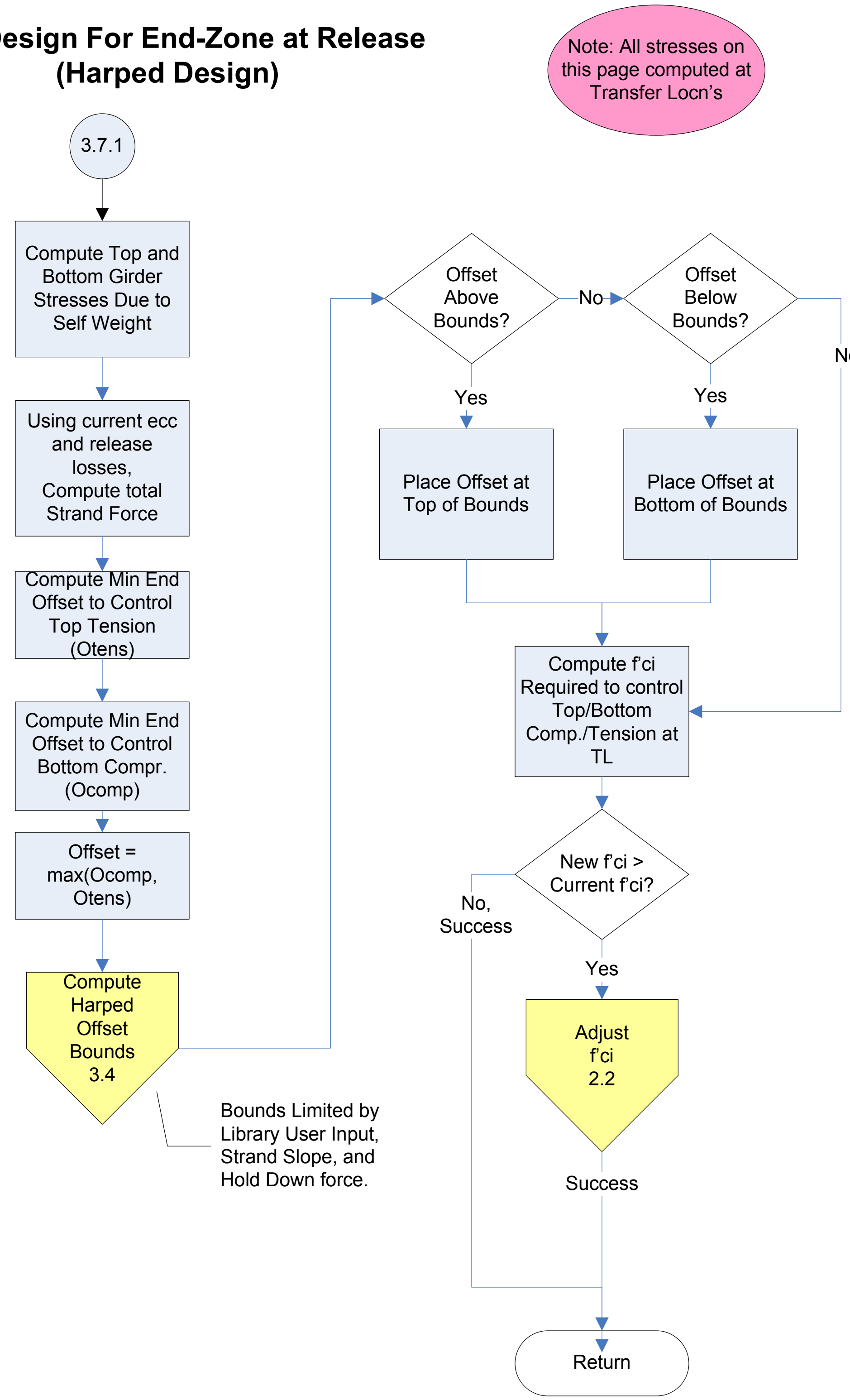
3.6 Design End Zones (Harped Design)



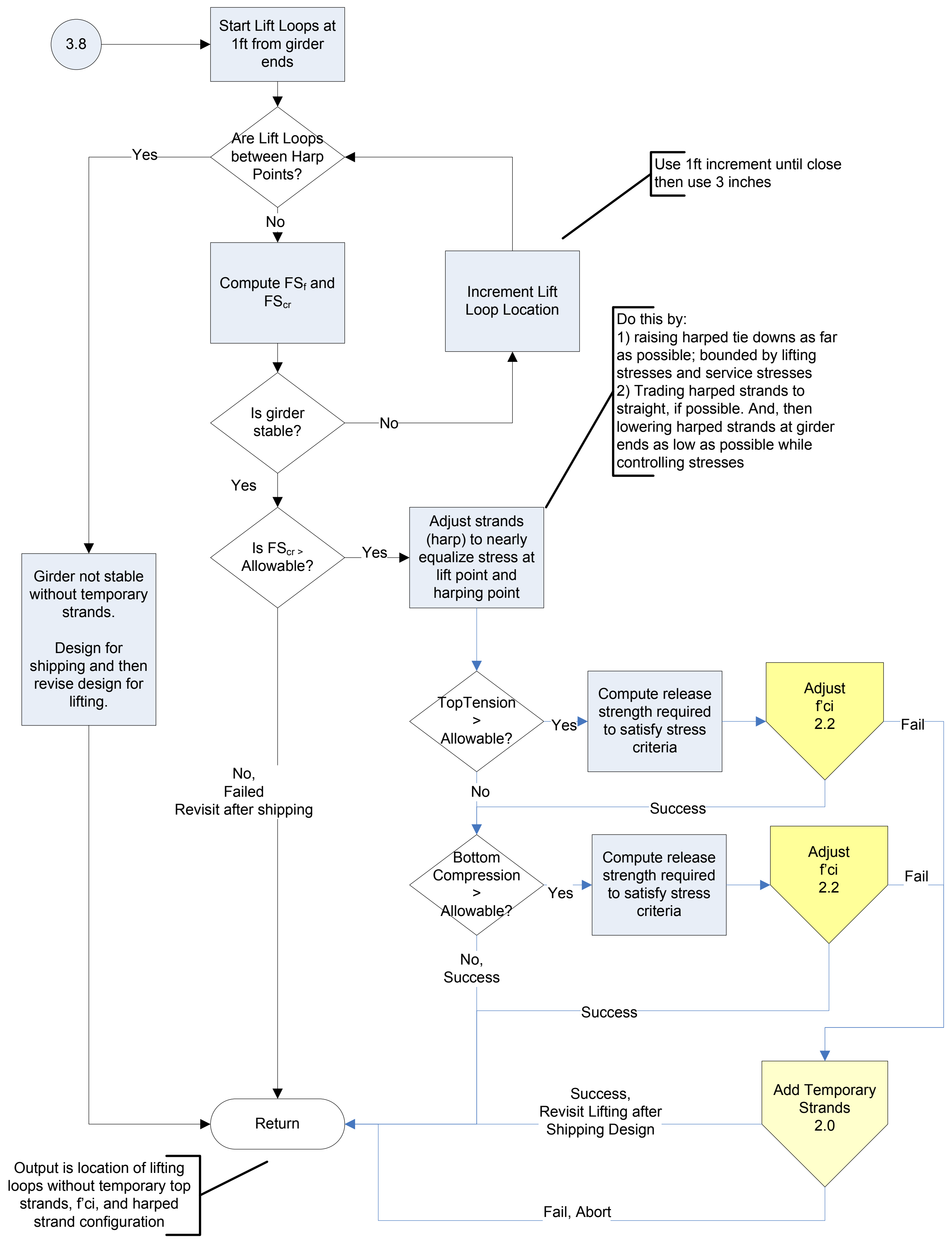
3.7 Design For End-Zone at Release (Harped Design)



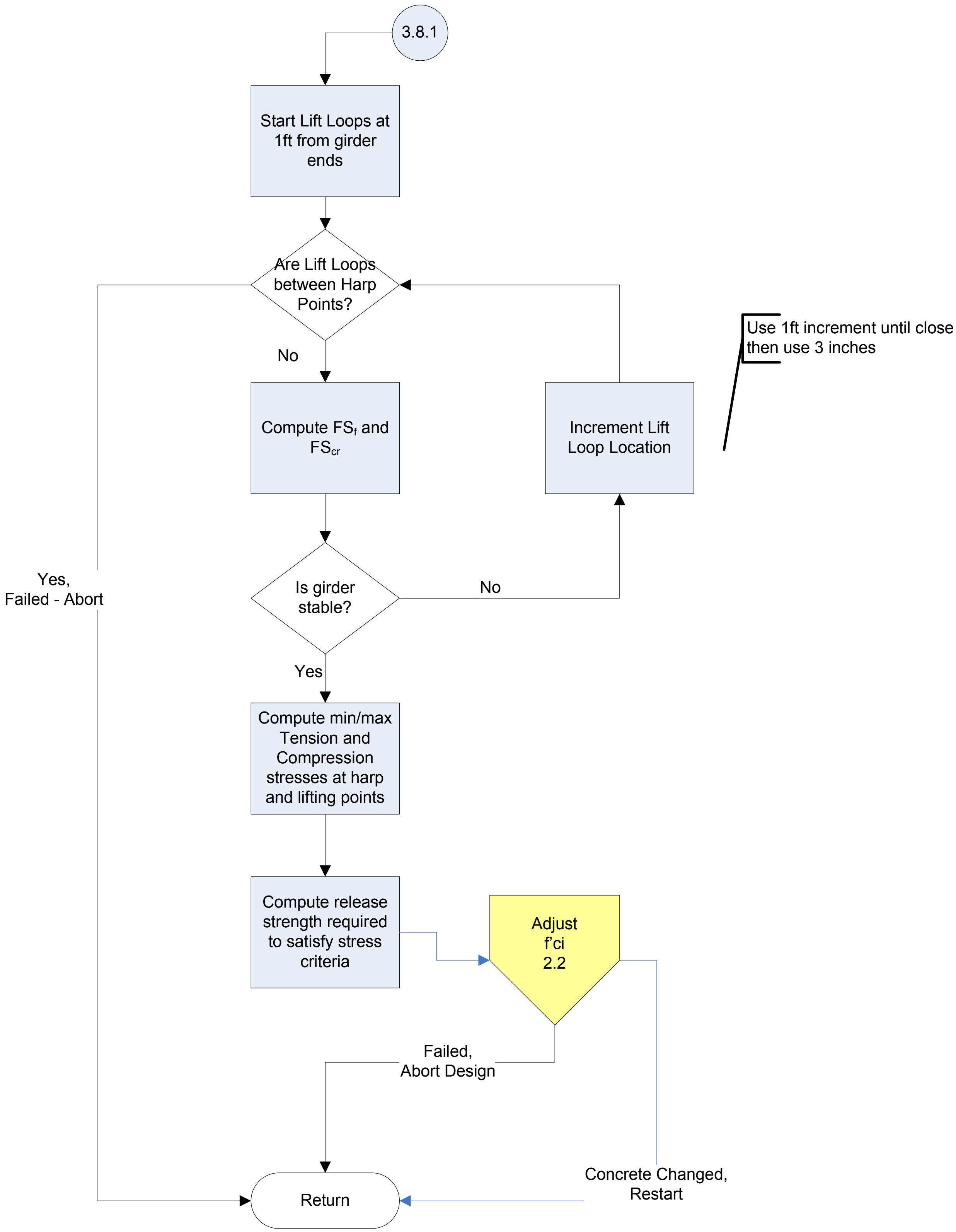
3.7.1 Design For End-Zone at Release (Harped Design)



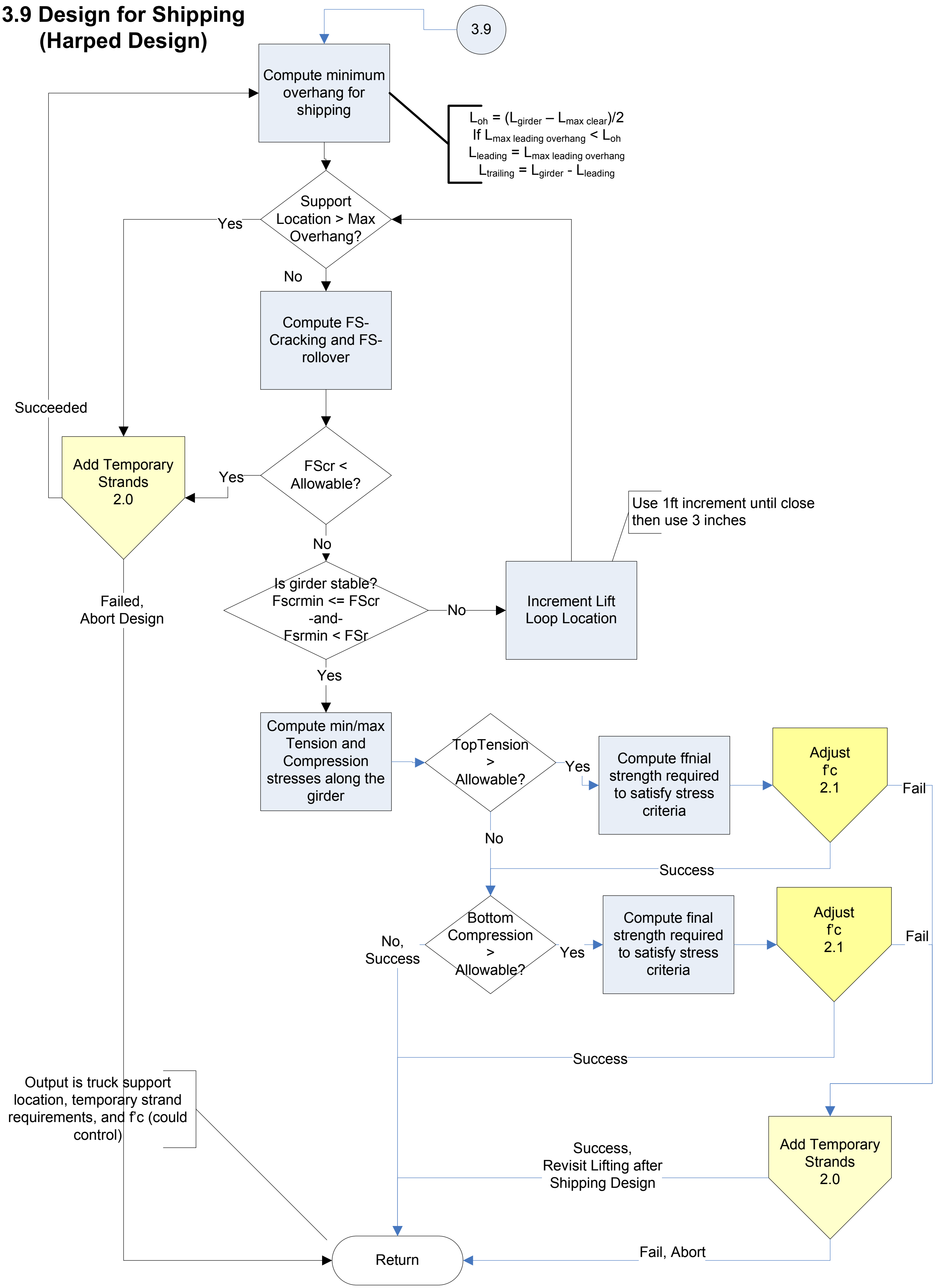
3.8 Initial Design for Lifting in Casting Yard (Harped Design)



3.8.1 Adjust Design for Lifting (Harped Design)

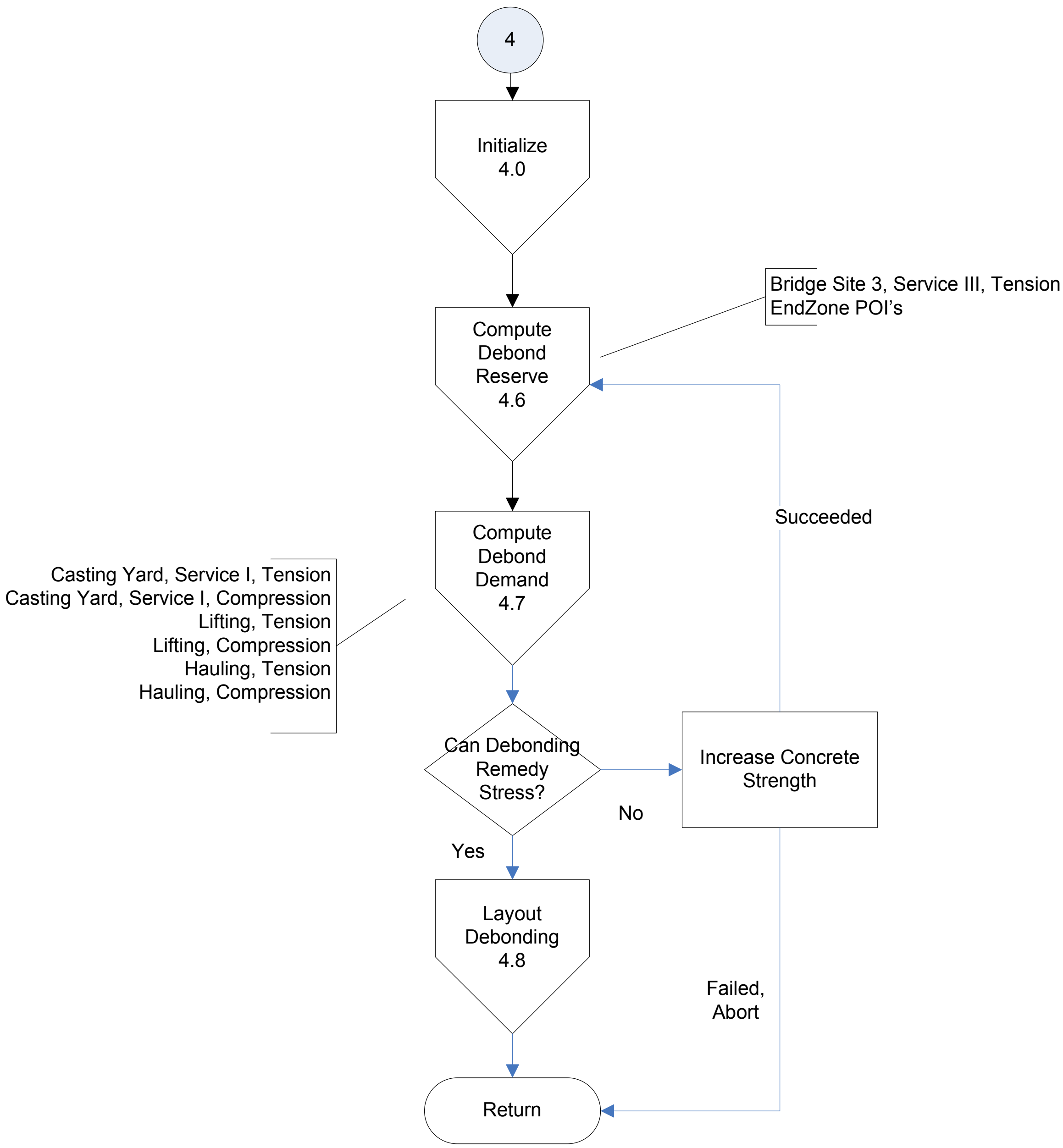


3.9 Design for Shipping (Harped Design)

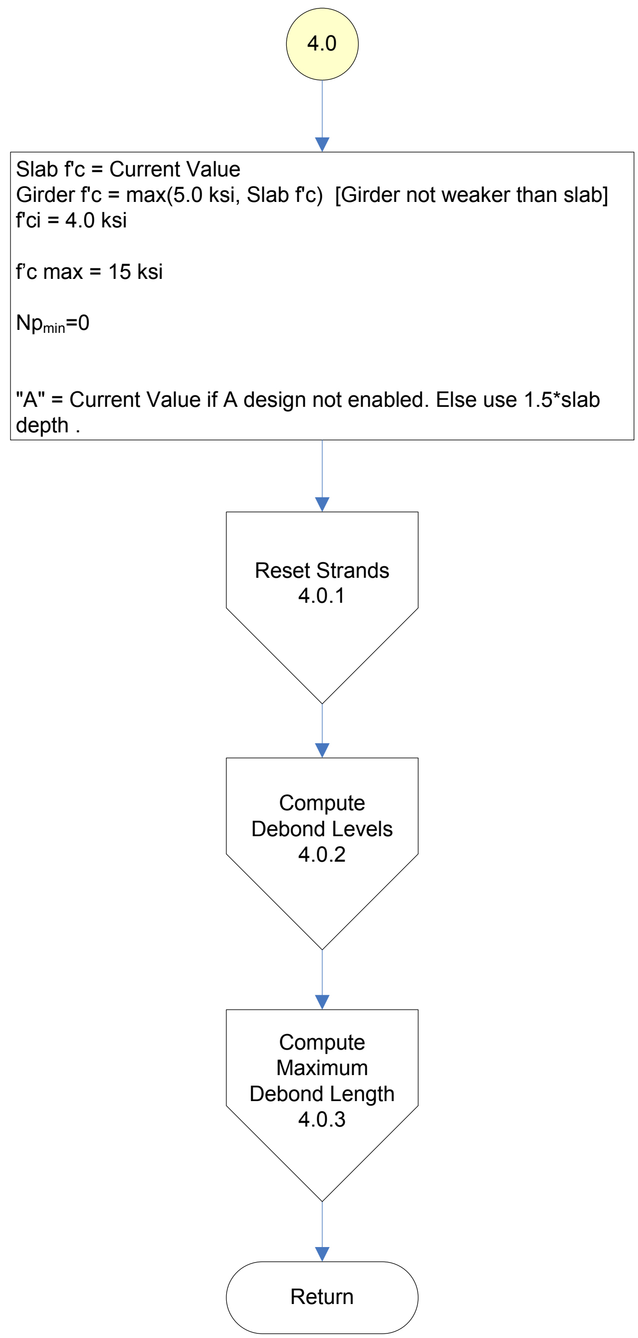


4 High-Level Debond Conceptual Design

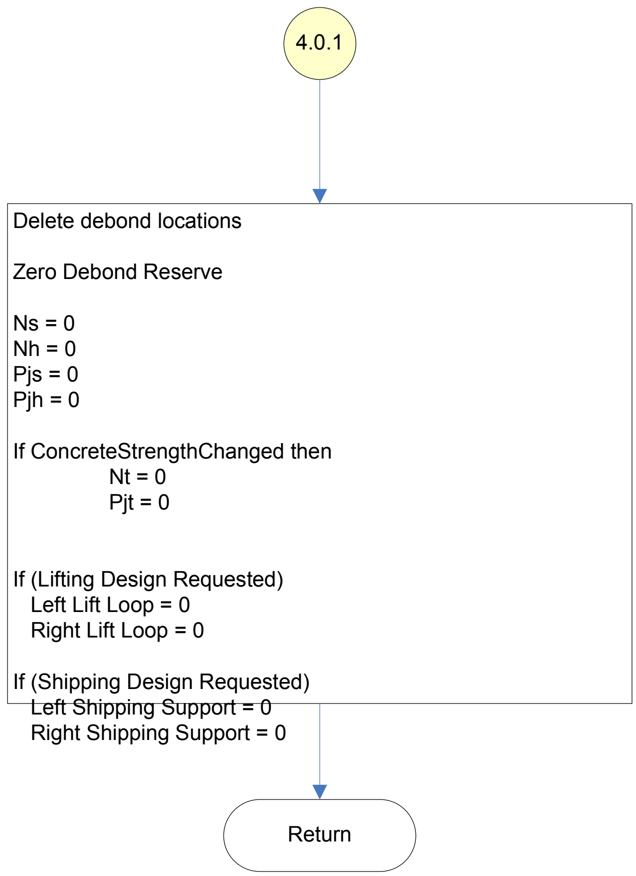
The following flowchart shows debond design at a conceptual level to show how debond design fits into the main design algorithm described in Section 1.0 of the main flowcharts. Note that the following is not called from any other flowcharts



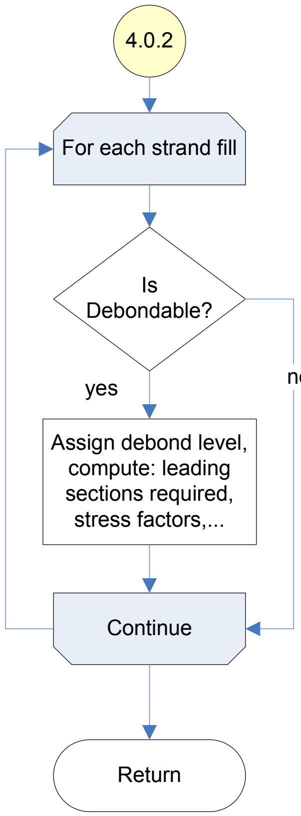
4.0 Initialize Design Parameters (Debonding)



4.0.1 Reset Parameters (Debond Design)



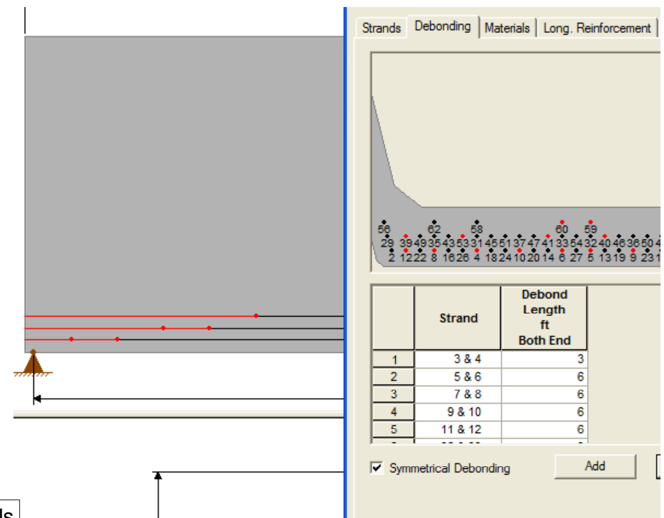
4.0.2 Compute Debond Levels



We have rules that define the exact ordering of debonding for any given section. For instance, the debond design order is the same as the fill order for strands, with the exception that some strands may not be debonded (exterior strands, for instance). Hence, at any debond section location, we can define an integral “Debond Level” that describes how many strands are debonded at that section. For example, in the figure below, Debond Level 1, would mean that strands 3 & 4 are debonded at the section; Debond Level 2 means strands 3&4,5&6; and so on...

The most basic limits for debond levels at any given section are controlled by geometric concerns, and user-specified debond limits at rows, sections, and percentage of total number of strands.

Note that Debond Level data is not dependent on loading and does not change during design. Hence this data can be pre-computed and reused throughout the design process.



Some Higher Debond Levels cannot be achieved unless additional debonding occurs at one or more interior sections.

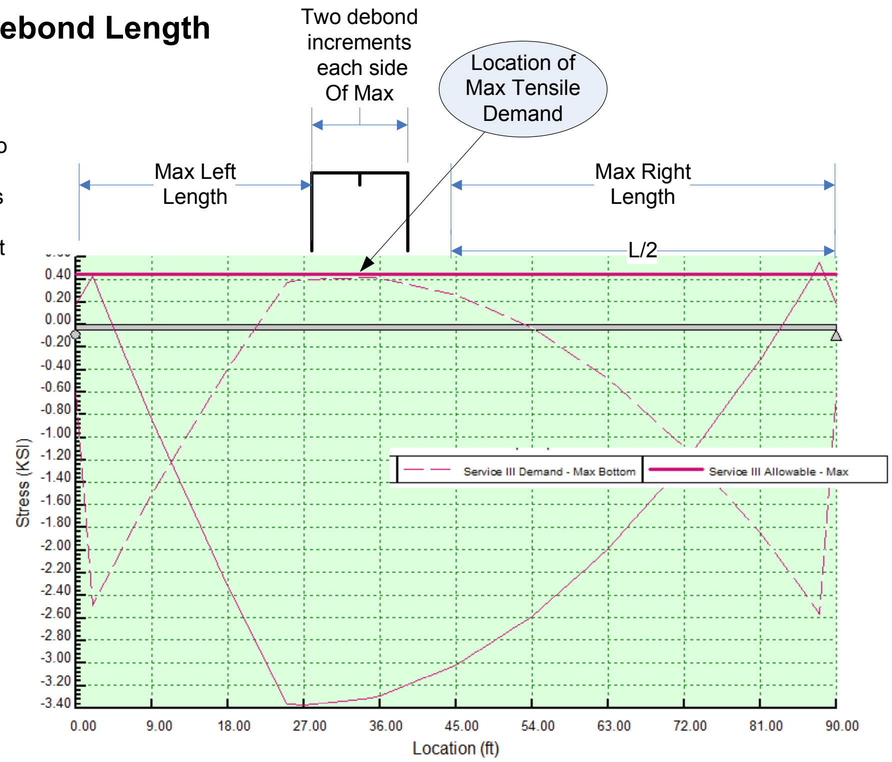
Debond Level	Strands Debonded	Minimum # of Strands for Level	# of Leading Sections Required	Min Level at Next Leading Section	Top Stress Factor	Bottom Stress Factor
1	3,4	4	0	0	-1.2	2.3
2	5,6	4	0	0	-2.2	3.5
3	7	6	0	0	-3.3	5.6
4	8,9	6	1	1	-4	6.7
5	11,12	8	1	2	-5	7.8
…	…	…	…	…	…	…

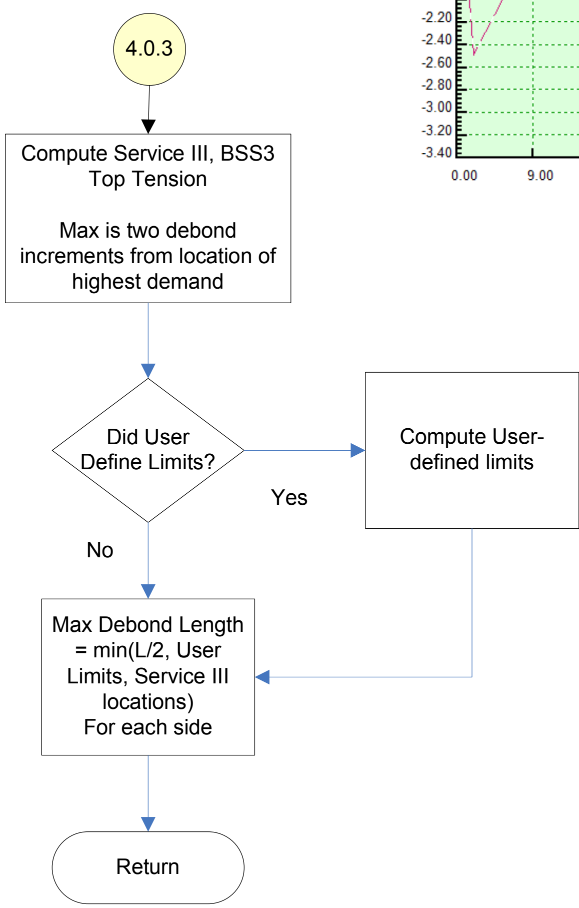
This table is generated after loops are complete:

Multiply the average prestress force per strand (including losses) to get the stress reduction from this level

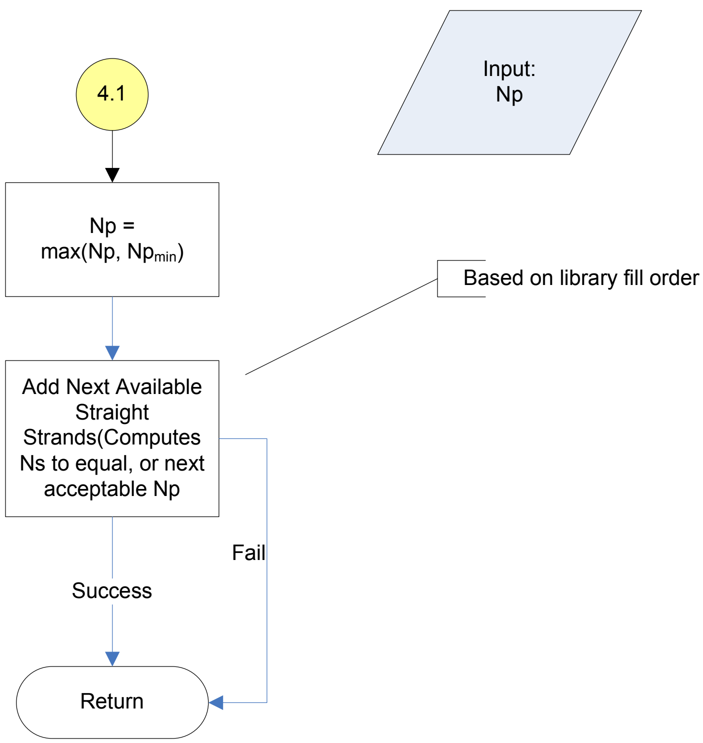
4.0.3 Compute Maximum Debond Length

The maximum debond length is defined as the minimum of: 1) one-half of the girder length, 2) the user-defined limits, and 3) two debond increments from the location of maximum tensile demand for Service III. As shown in the figure of a structure with a large, off-center point load; the left and right max debond lengths do not have to be equal.

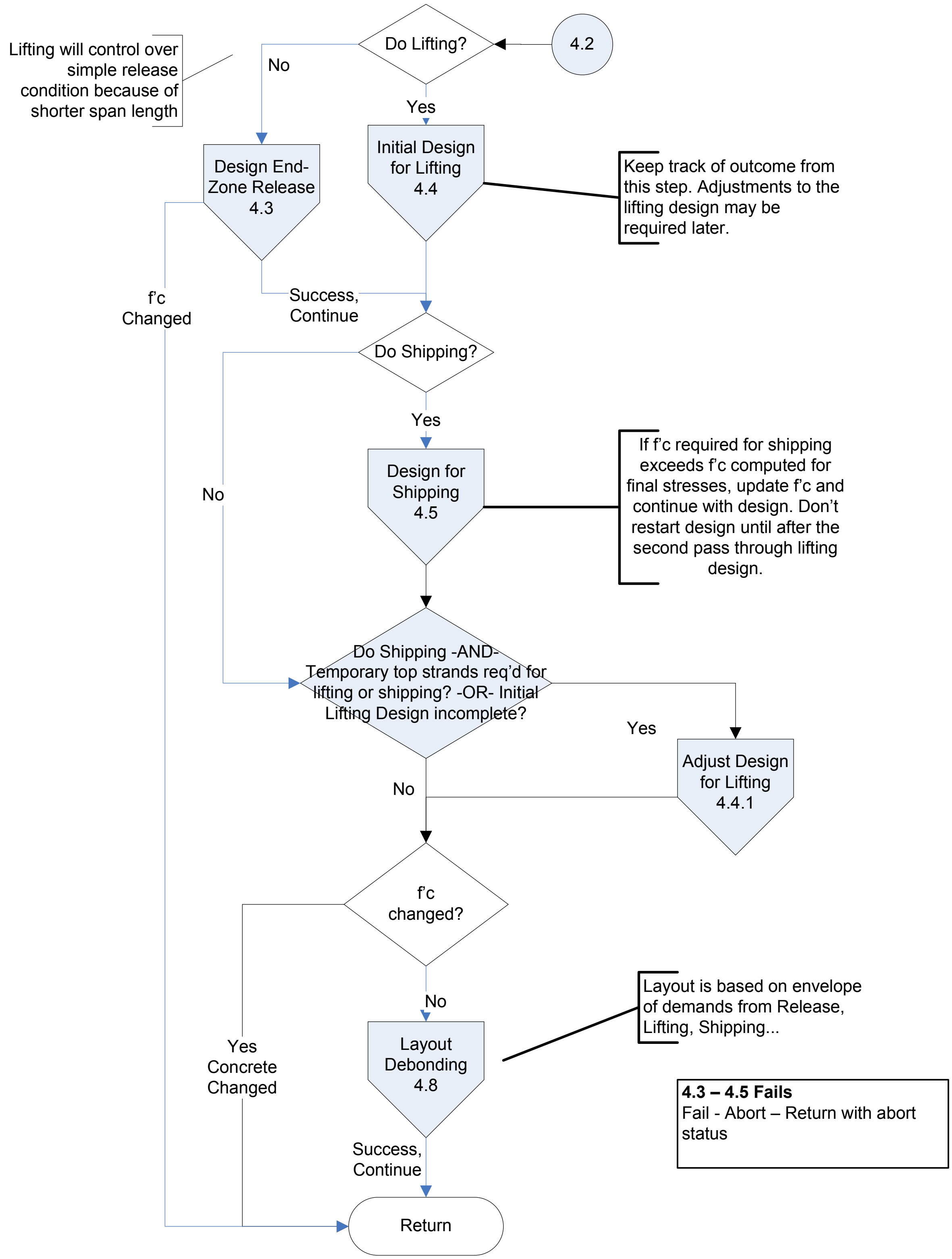




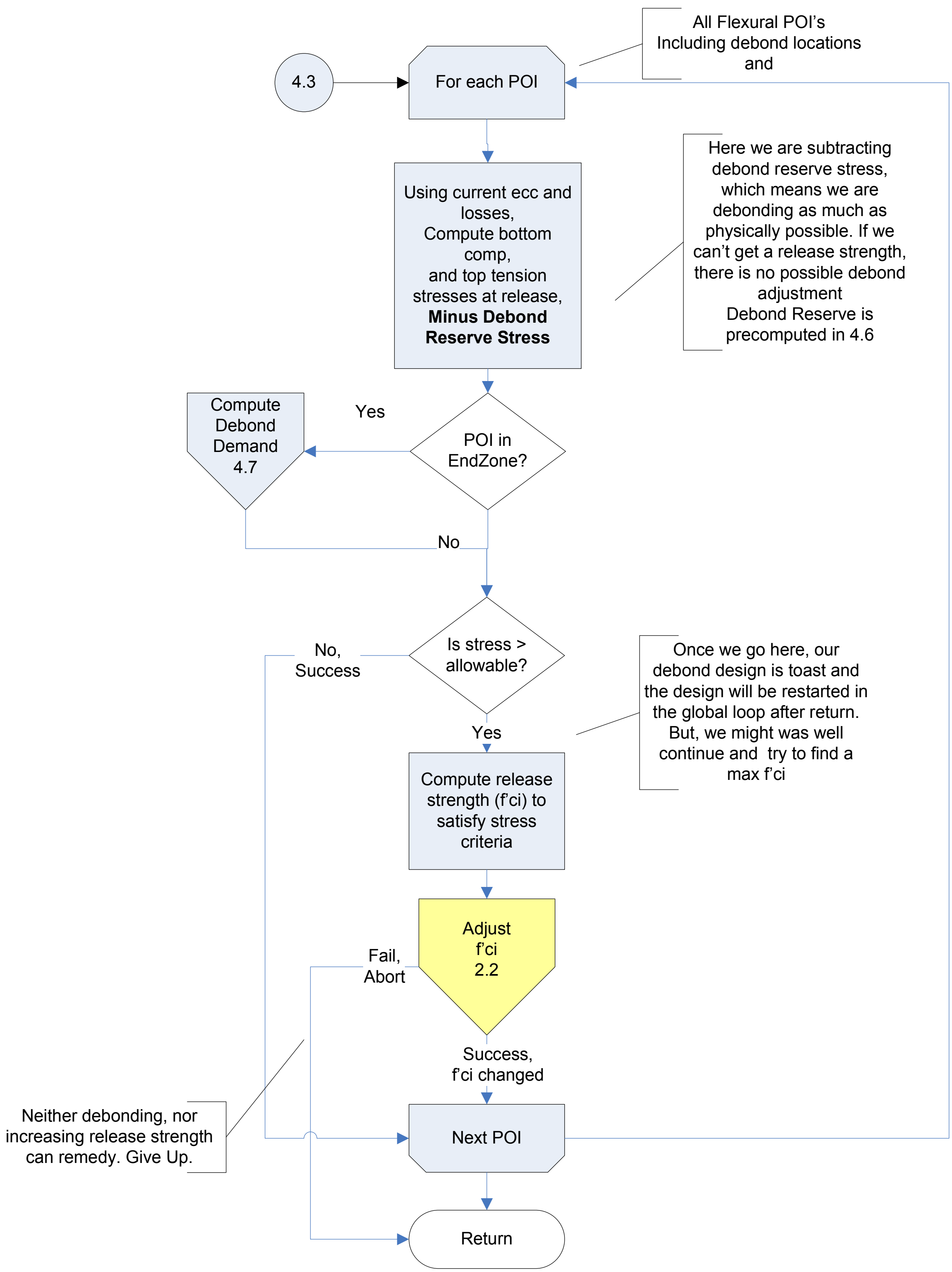
4.1 Proportion Strands (Debond Design)



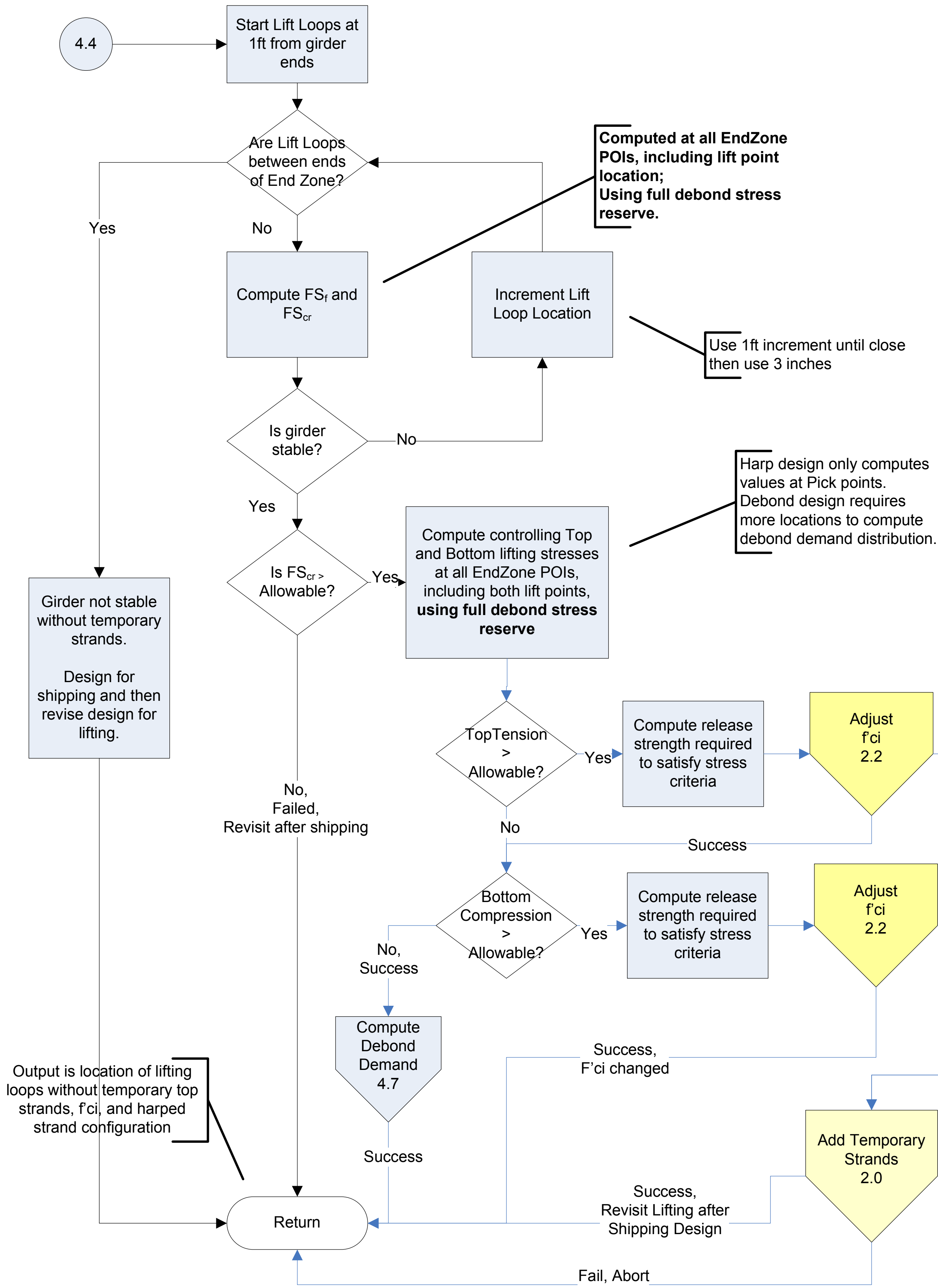
4.2 Design End Zones (Debond Design)



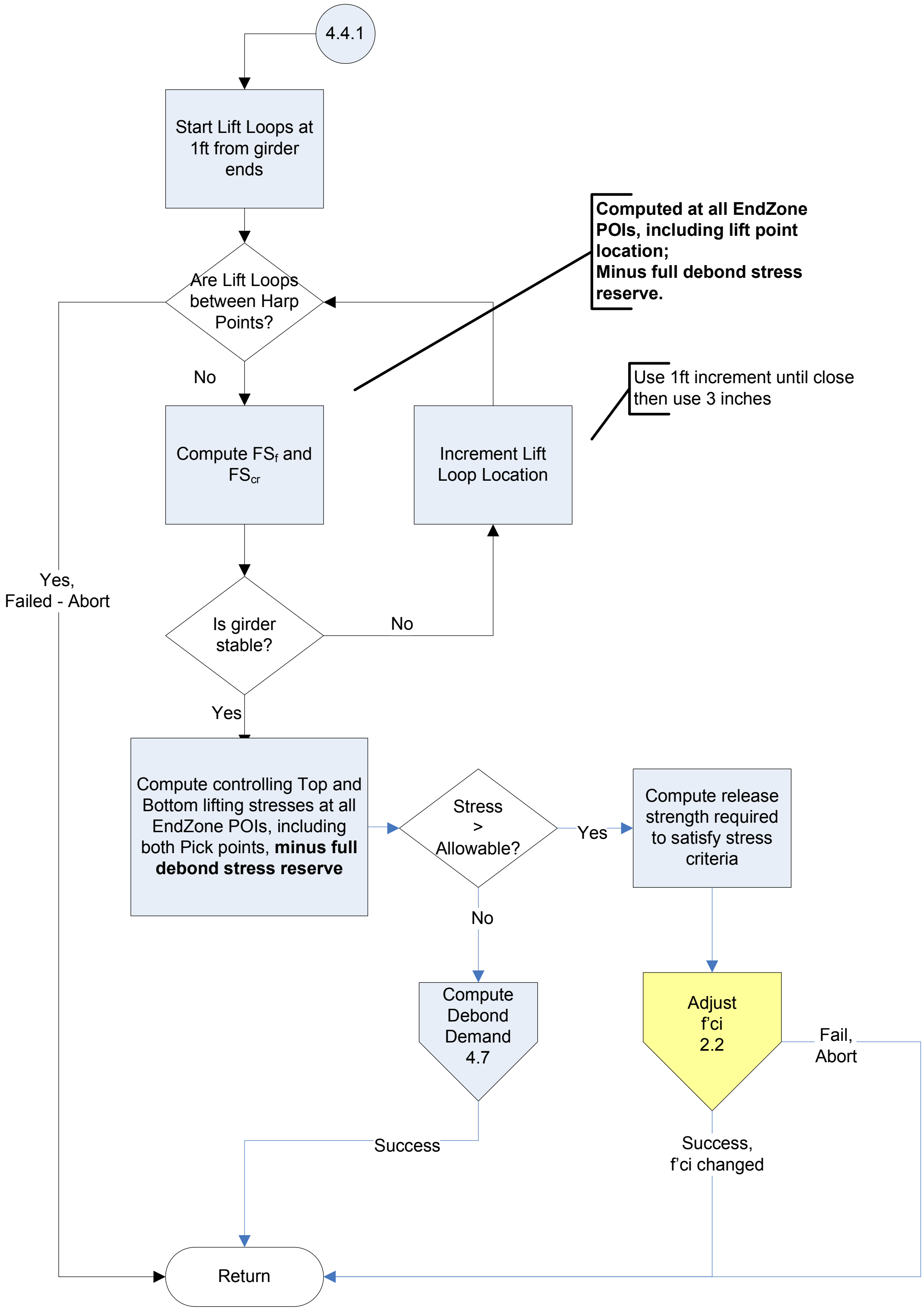
4.3 Design For End-Zone at Release (Debond Design)



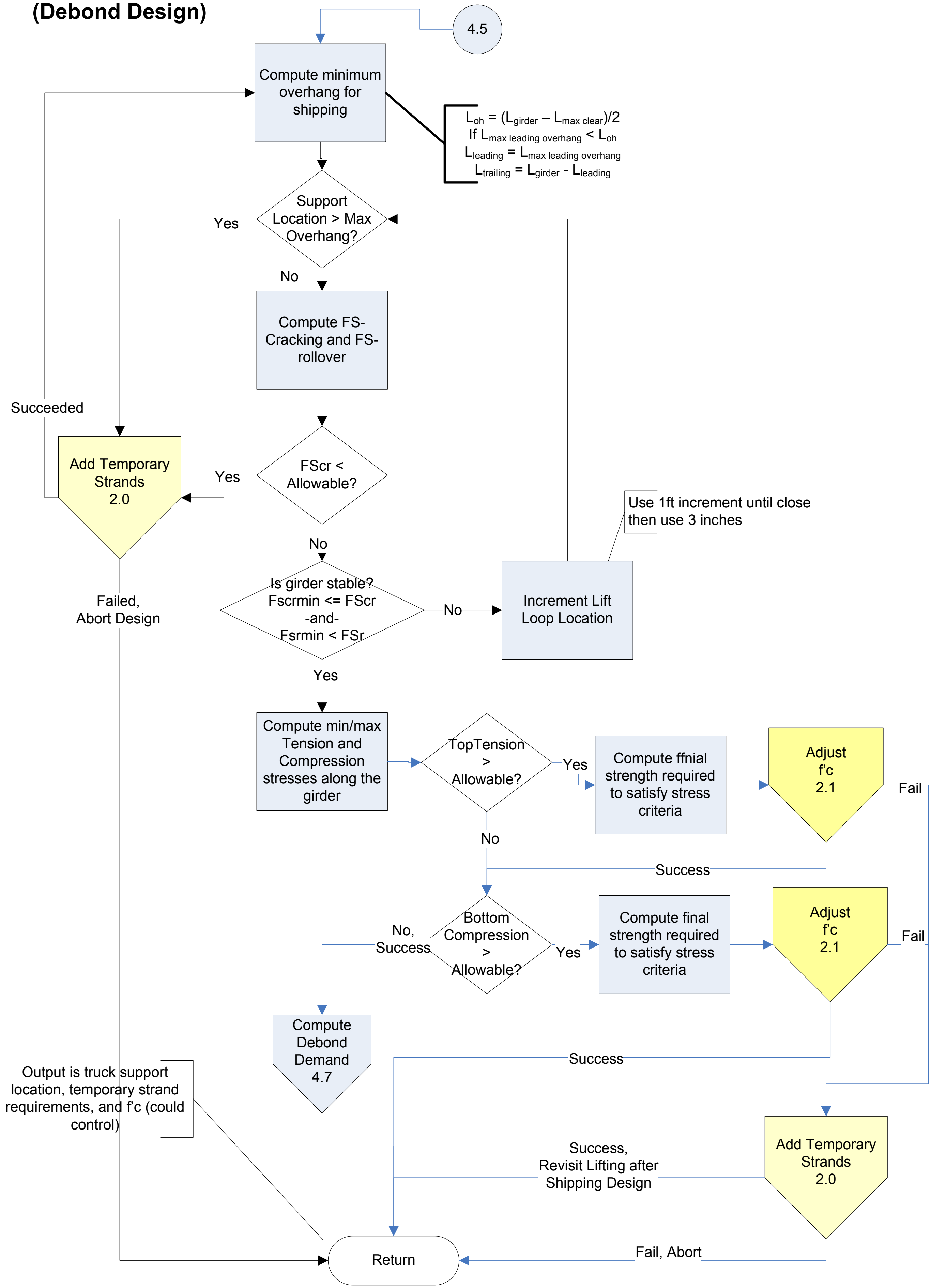
4.4 Initial Design for Lifting in Casting Yard (Debond Design)



4.4.1 Adjust Design for Lifting (Debond Design)



4.5 Design for Shipping (Debond Design)

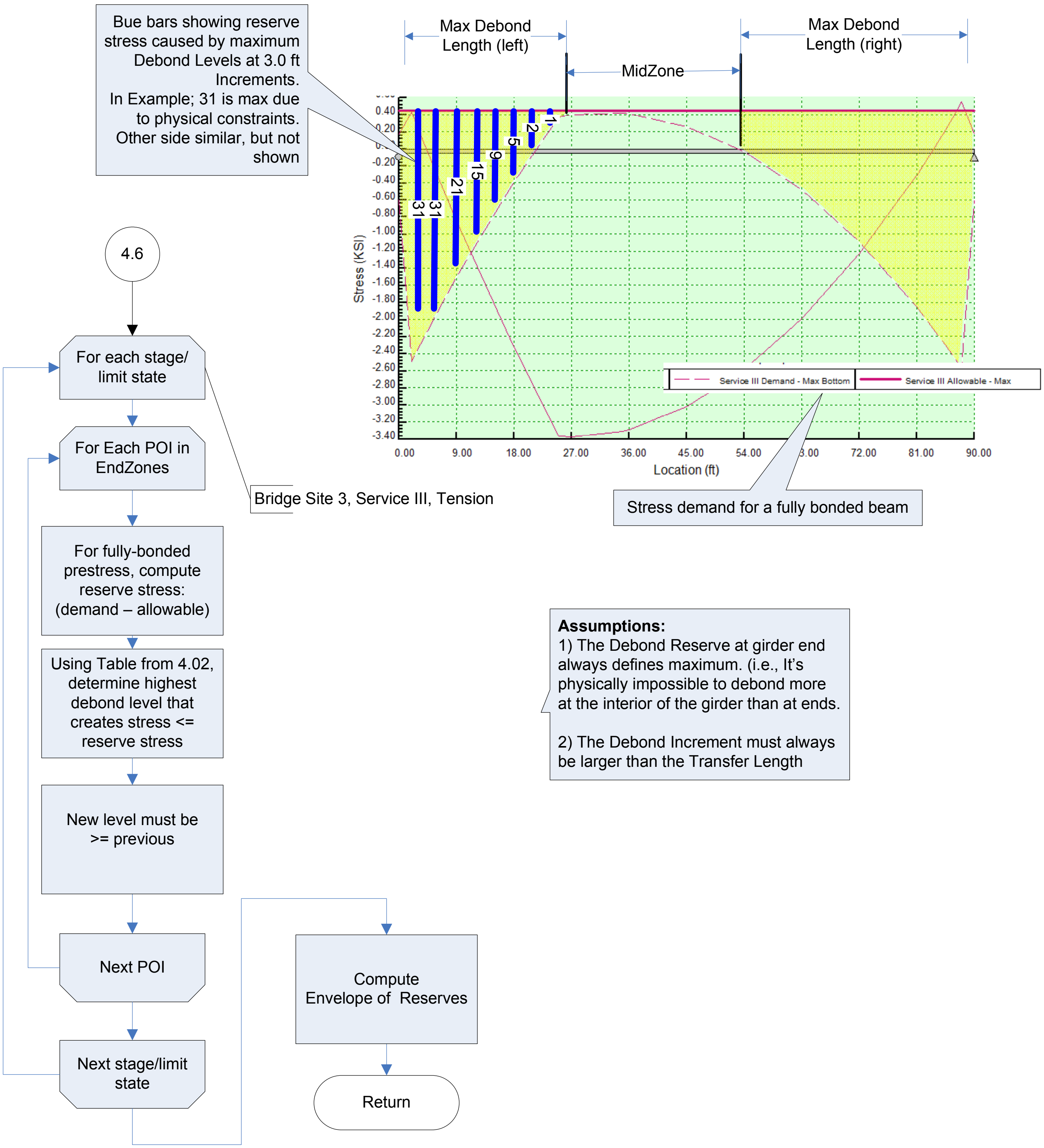


4.6 Compute Debond Reserve

Excessive debonding can be too much of a good thing. For instance, debonding can cause Service III bottom tensile stresses to be violated. The concept of Debond Reserve is used to prevent over-debonding.

The Debond Reserve is defined as the maximum Debond Level that can be applied at a section location such that stress limits are not violated. For example, the figure below shows Service III stress demand for a girder with all bonded strands, and supporting a very large eccentric load. The areas in yellow show the amount of stress that can be added by debonding without causing tensile failure. The blue bars indicate the max allowable discrete Debond Level for each location.

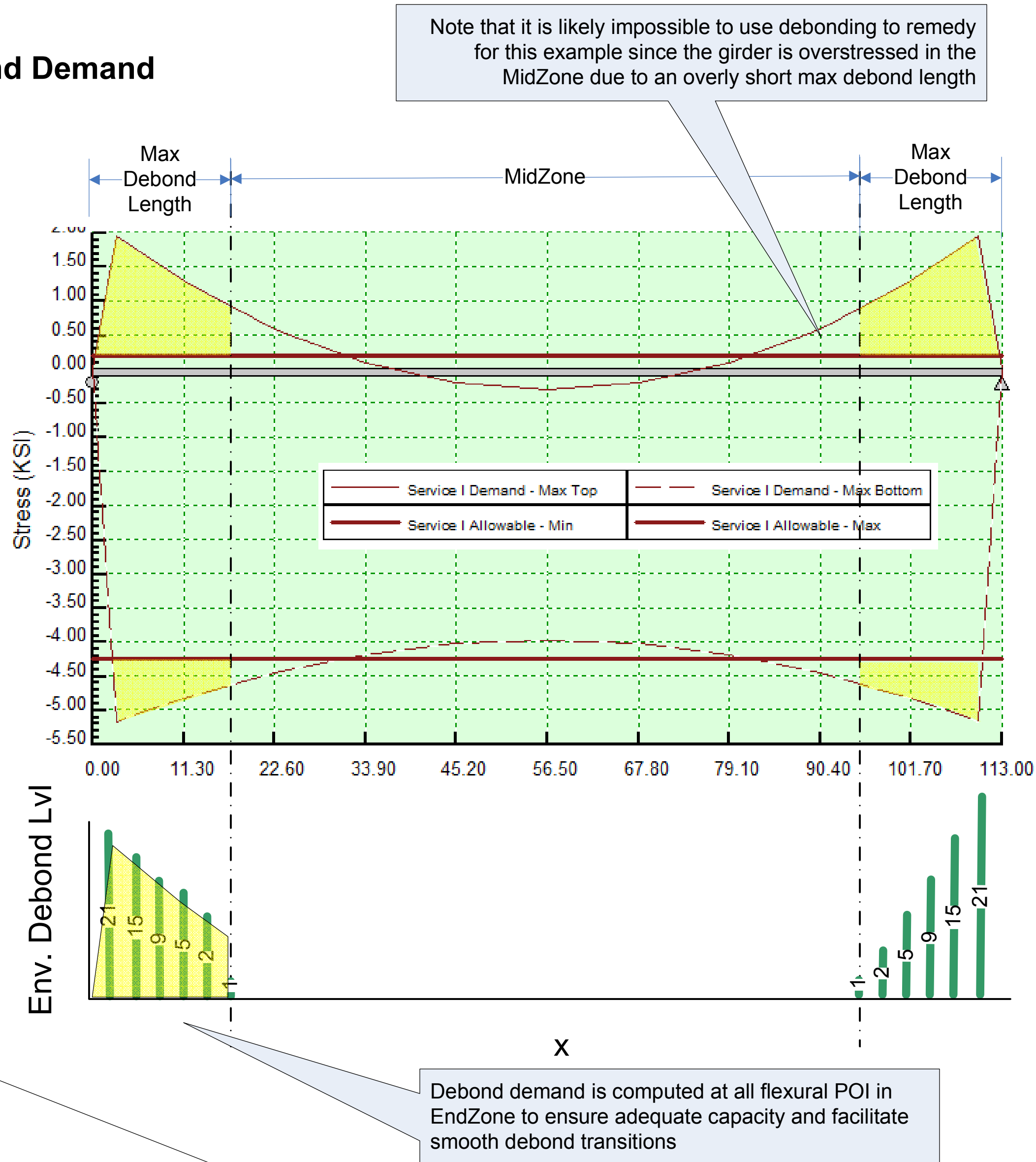
Note Debond Reserve can be computed for all limit states where over-debonding is an issue. An envelope of all Reserves then can be computed to determine how much debonding can be applied before overstressing.

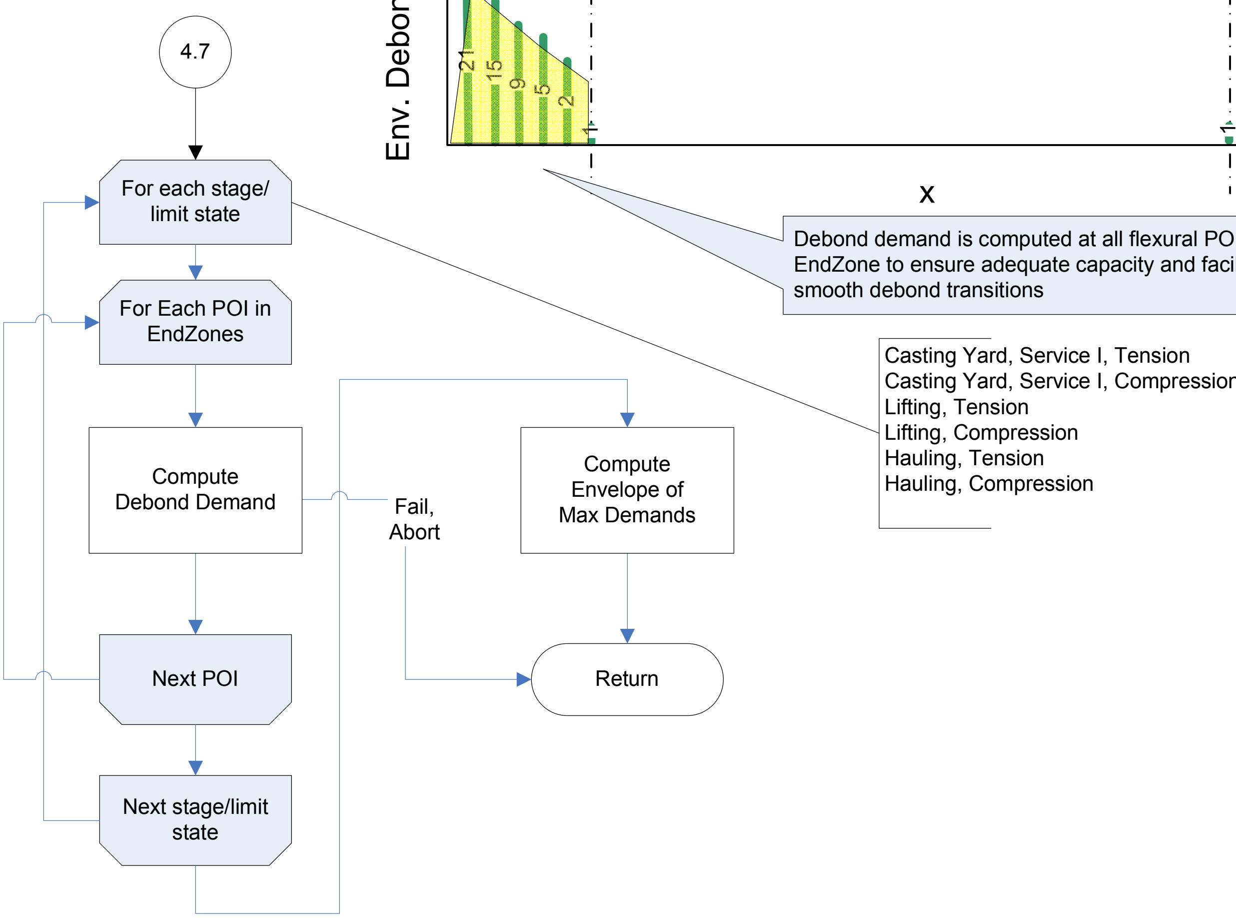


4.7 Compute Debond Demand

Debond Demand represents the Debond Level required at a location to prevent overstressing. The yellow areas in the figure to the right represent the stresses that must be reduced by debonding in order to avoid overstressing. As mentioned before, a debond level required to satisfy stresses can be computed for each given stage/limit state/location. The Debond Levels are shown as green bars in the figure. These debond levels can then be enveloped to find the total required level of debonding.

If debond demand exceeds the allowable debond level, this function will fail.

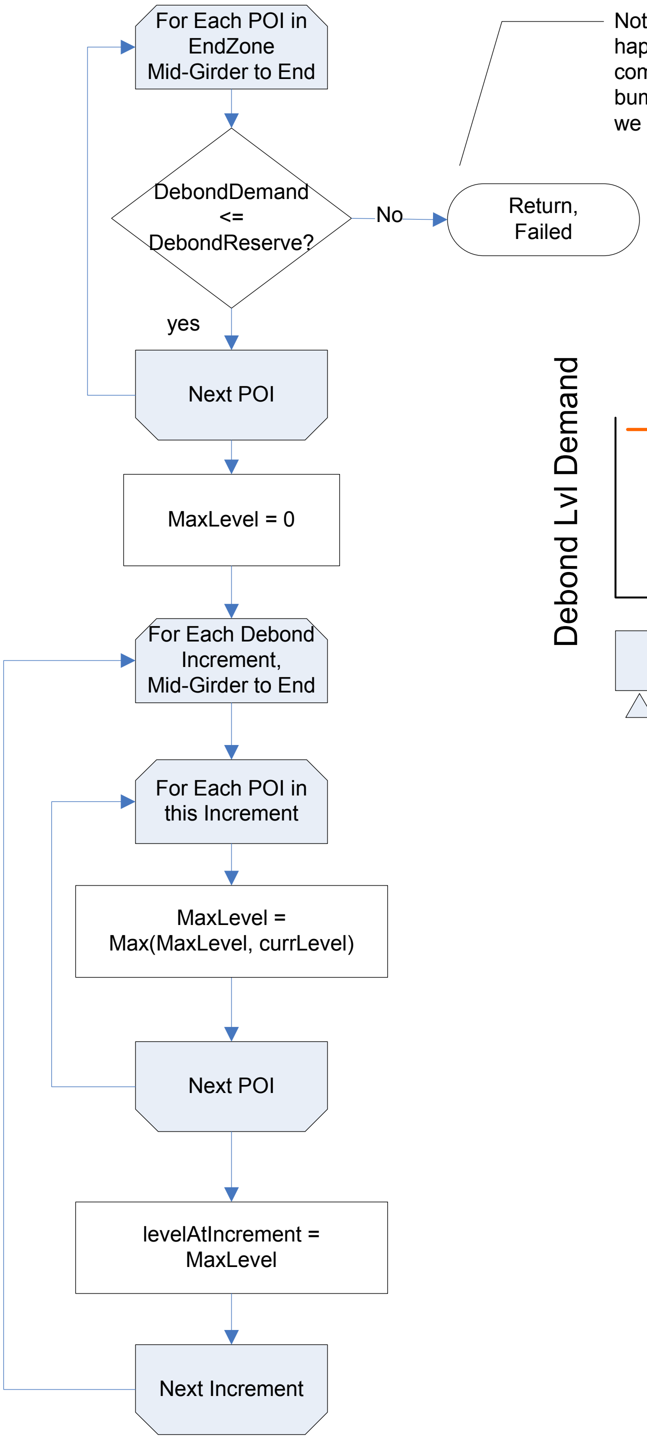




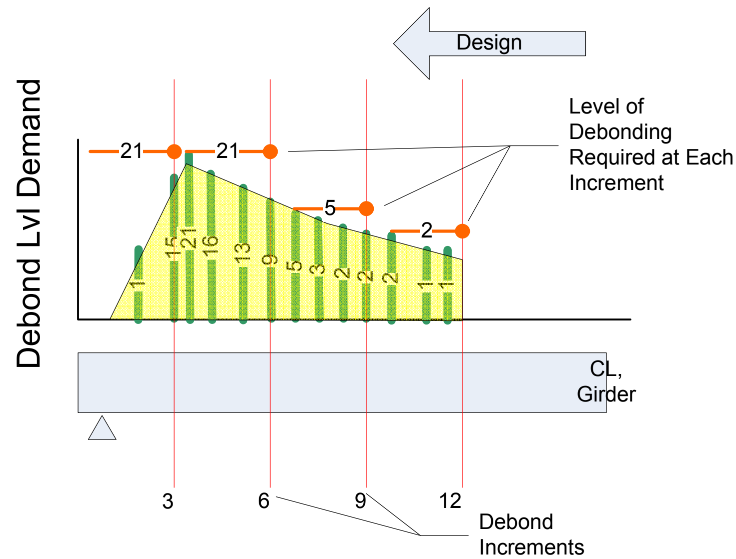
4.8 Layout Debonding

Enveloped Values of Debond Demand Levels. We cannot continue if inadequate reserve

Note that this should never happen here because stress comparisons will fail and try to bump concrete strength before we get here.



Note: This algorithm does not account for transfer length



Work Plan for Prerequisite Issues for Debond Design

Version 1.1 – 3/14/08

Revisions

Draft Version 3

- Added debond increment length
- Removed Debonding from Project Criteria library and moved it to Girder library
- Added ability to specify which strands are allowed to be debonded.

Final Version 1.0

- Full length debonding is not to be done.
- Design with debonded lengths decreasing inward will be the default. This will not be checked.
- Staggered strands wrt rows can be enforced by library entry of debondable strands. This will not be checked.

Version 1.1

- Remove minimum release strength prior to debond design.

Background

The goal is to update PGSuper to satisfy TxDOT and WSDOT requirements for debond analysis and eventually a design algorithm for debonded girders. This document describes changes required for this implementation.

User Interface Changes

The current version of PGSuper supports analysis for LRFD debonding; however TxDOT has additional debond length requirements to be supported by changing the UI follows:

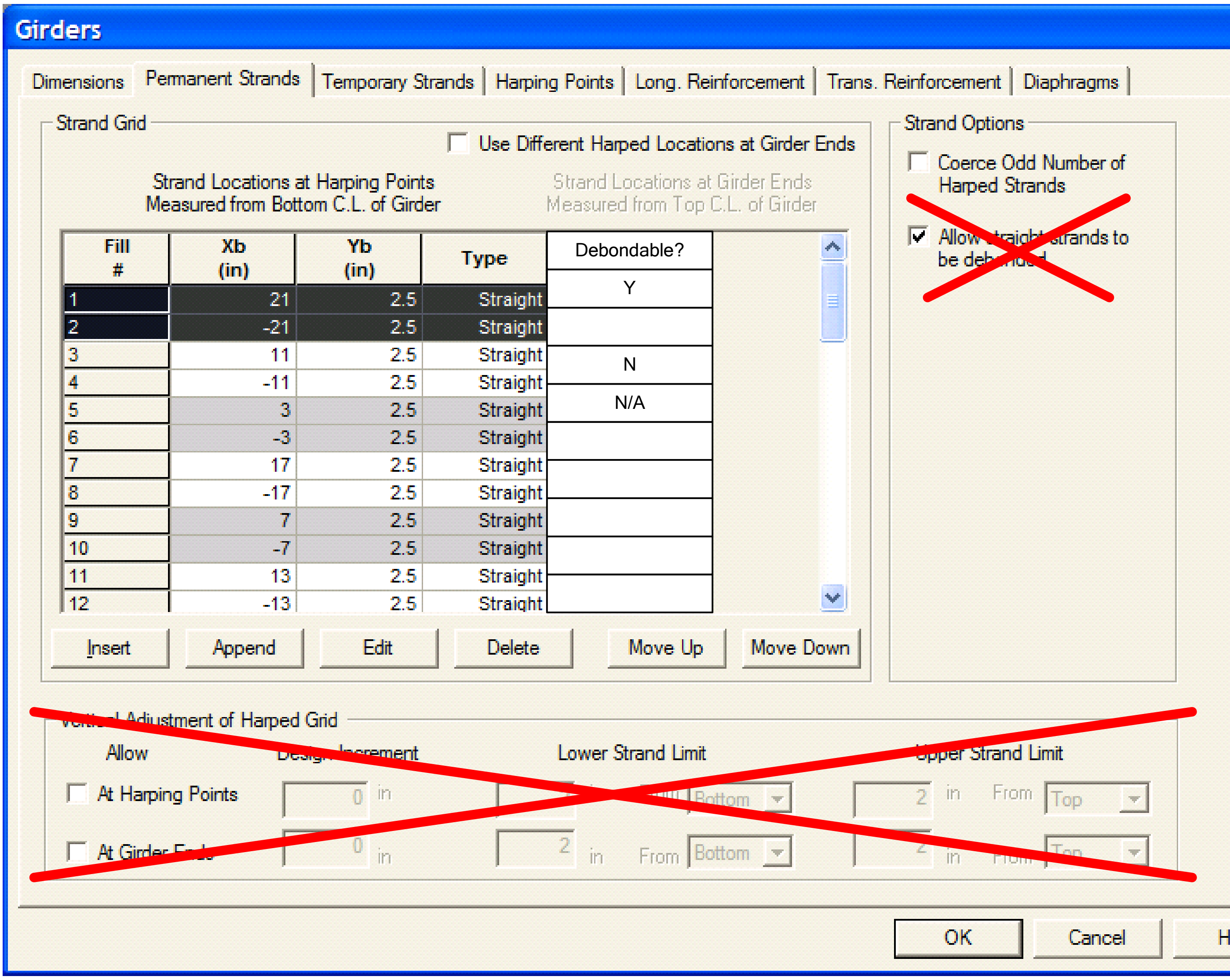
Project Criteria Library - Debond Tab - Remove

It has become clear that debonding options vary between girder types. Hence, the Debond tab will be completely removed from the Project Criteria library, and relocated to the Girder Library.

Existing debond data from older versions must be accommodated. If, on the Girder Library – Permanent Strands Tab, the “Allow Straight Strands to be Debonded” option is checked, the debond information from this tab will populate the debond information for that girder. Otherwise the girder will not have any debonding limits defined.

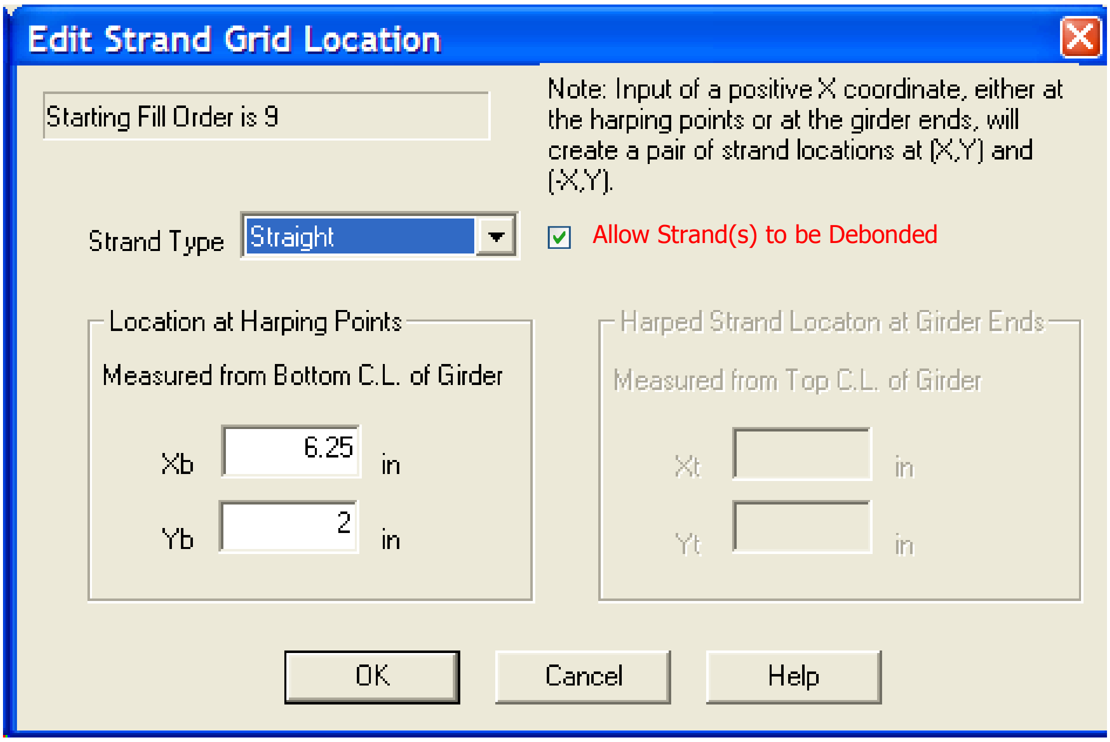
Girder Library – Permanent Strands Tab

The "Allow straight strands to be debonded" option will be removed from this tab and placed on a new Debond Criteria tab. The "Vertical Adjustment of Harped Grid" options will be moved to the Harping Criteria tab. This will create more room for the strand table:



Girder Library – Permanent Strands – Edit Strand Locations Dialog

Currently, the determination of whether/which straight strands may be debonded is all-or-nothing. It has become clear that this choice is complex and sometimes agency dependent, so it is more appropriate for the library builder to choose debondable strands than it is for a design algorithm, or even an end user. Hence, the Strand Grid Location dialog will be modified to allow choice of debondability of individual strand(s) as shown below:

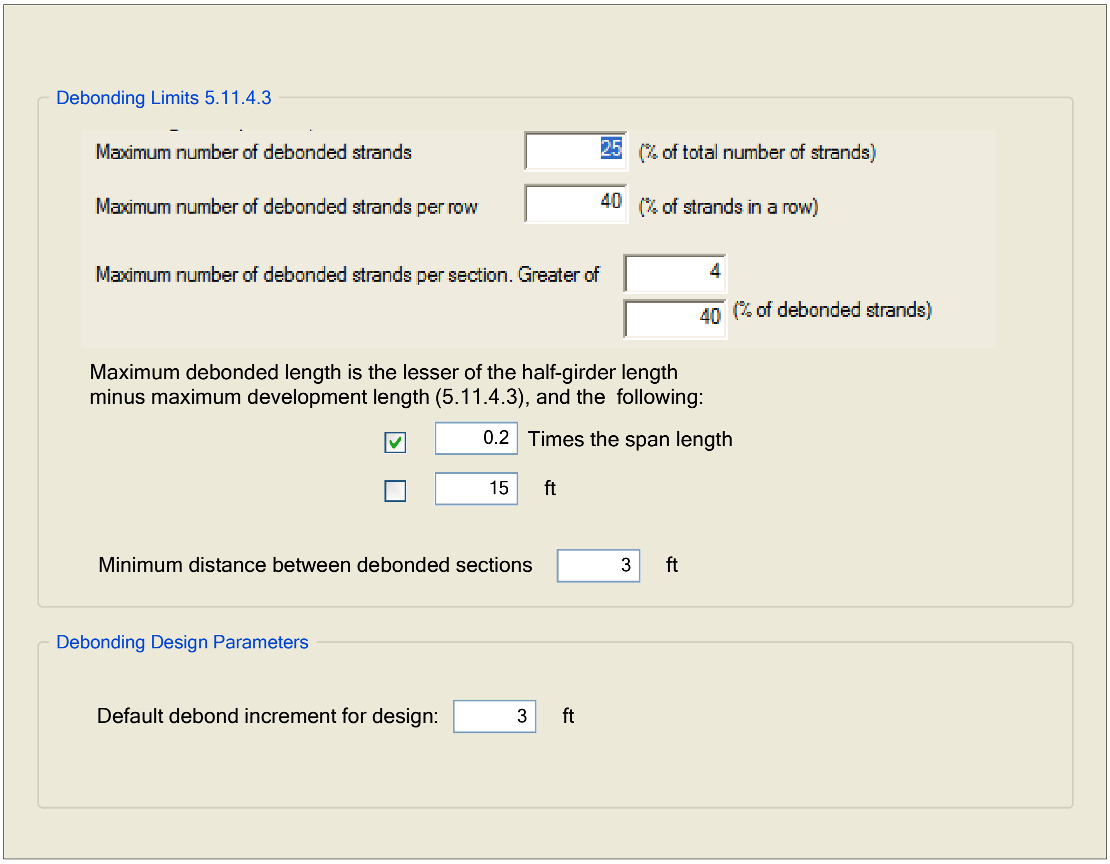


The addition of this feature will also necessitate discrimination of debondable/not-debondable strands in the section display in the girder library section view and the section view in the Girder Editing Debonding tab.

This feature will allow rules like "debonding is to be staggered in each row" to be easily enforced by librarians.

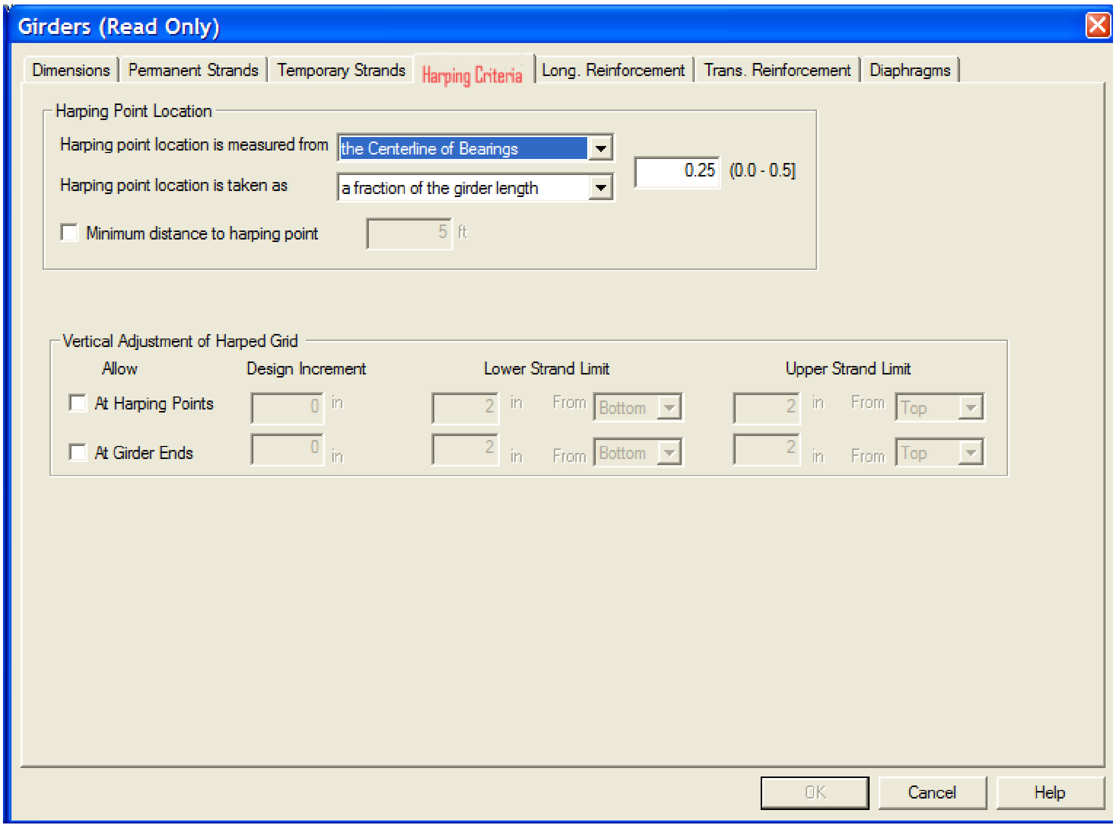
Girder Library – Debonding Criteria Tab - NEW

All debonding criteria from the Project Criteria dialog will be moved to this tab and options to specify maximum debond length, minimum distance between debonded sections, and minimum release strength for debond design will be added as shown below:



Girder Library - Harping Criteria Tab – Renamed

Rename the Harping Point tab to Harping Criteria and move the Vertical Adjustment data from the Permanent Strands tab to this tab.



Status Center

Create a level 2 (yellow) status entry if any strands are debonded beyond the user-specified limits. The analysis will continue, but resulting in a Failed Spec Check. Direct user to the Girder Editor – Debonding tab to remedy.
Create a level 2 (yellow) status entry if any strands are debonded and the release strength is less than the minimum for design (e.g., 6ksi).
Create a level 2 (yellow) status entry if the debond increment for design is less than the prestress transfer length for the current strand type.

Spec Checking / Analysis / Design

A Fail will occur in the Specification Check if any debonded length exceeds the defined maximum. This must be reported in the Specification Check Report, the Details Report, and the TxDOT/WSDOT Summary Reports.

Debond design will be done at all analysis points between the end of the girder and the max debond length plus transfer length from the end. Analysis points will be placed at:

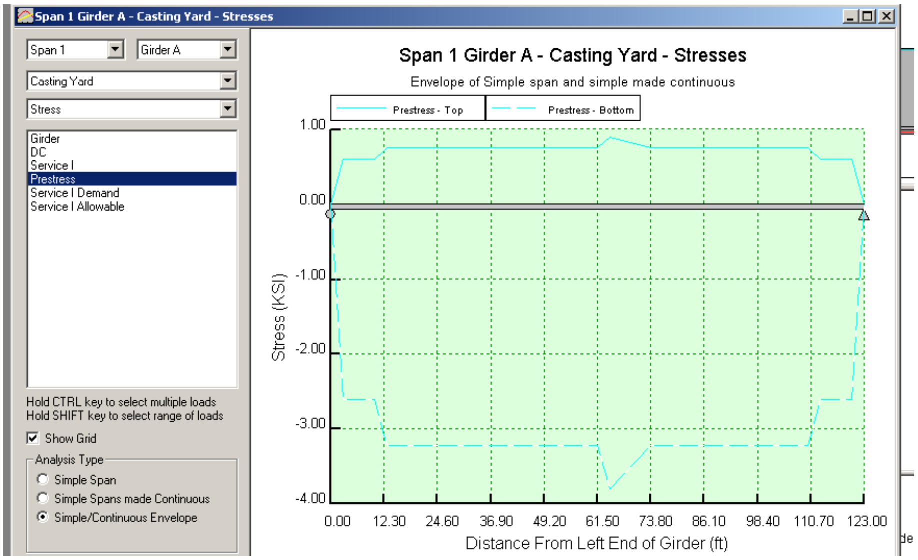
1. Span or girder length tenth points
2. Debond Locations
3. Debond + TL locations
4. Load locations
5. H from the end of the girder or from support
6. Critical Section for shear

Reporting

1. Report max debond length in Project Criteria chapter
2. Add max debond length check to Spec Check Report. The Spec Check will fail if over-debonded strands exist.
3. Report min distance between debond sections in Project Criteria chapter
4. Add min distance between debond sections check to Spec Check Report. The Spec Check will fail if sections are too close.
5. Strand Eccentricity table does not collapse Point of Interest (POI) locations. This should be changed so that only one set of data per location is output so as to conserve report space.
6. Currently POI’s for all analysis results are created at debond locations and at transfer-length (TL) from the debond locations. This practice will continue.
7. The TxDOT CAD report must be enhanced to include debonding data. This is defined in BT issue #59.

Bugs

1. Here is a prestress stress graph for 61.49’ debond of a 123’ girder. This only happens if a debond location is less than the transfer length to mid-girder. This is obviously a bug and should be investigated whether or not we allow debond lengths into this region:



Design Algorithm

The main design algorithm document has been updated for debond design and this document is not considered an Appendix to that document.

For a conceptual overview of the debond design algorithm, refer to Flowchart 4 in the main flowchart Appendix.

Issues

None open at this time

Appendix C – Glossary of Terms

General Terms
Design Parameters – Variables that affect design
f'c – Final concrete strength
f'ci – Concrete strength at release
Strand Offset – Distance harped strand pattern is moved vertically from original library position at HP or End. Up is positive.
Ns – Number of straight strands
Nh = Number of harped strands
Nt = Number of temporary strands
Np = Number of permanent strands (Ns + Nh)
Np_{min}= Minimum number of permanent strands required for moment capacity
Pjs, Pjh, Pjt, Pjp – Pjack of straight, harped, temp, permanent strands
TL – Length of prestress transfer
HP – Harping point
End-Zone – Portion of girder outside of Mid-Zone
Mid-Zone – Portion of girder between, and including; harping points, or max debond boundaries. Always includes mid-span.
StrandProportioningMethod – This value is defined in the Specification Library and represents how straight strands are proportioned relative to harped strands. Two methods are possible:

-LibraryFill – Permanent strands are filled directly using library fill order

-Straight2HarpedRatio – Strands are filled attempting to maintain an X:1 harped to straight ratio.

Max Debond Length – Furthest distance from end where debond can occur.

List of Design Parameters
"A" Dimension – Distance from top of slab to top of girder at bearing location
BS1, BS2, BS3 – Bridge site stages in PGSuper
f'c - girder
f'c, - slab
f'ci, - girder initial strength
Harp Strand Offset – Girder Ends
Harp Strand Offset – Harping points
StrandProportioningMethod and Ratio, if req'd
Ns
Nh
Nt
Pjs
Pjh
Pjt
Lifting loop locations
Shipping support locations

Design outcome return codes
Success – Design succeeded, continue to next limit state
Abort – Design failed, cannot continue
Concrete Changed – Restart design from beginning with new strength
Restart – Design succeeded, but adjustment was made to strands. Keep strand design and recheck all criteria.