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Advancing AI Assisted Conceptual Design of Subsea Inline Structures: Mechanical Behaviour of Pipeline-Mounted Structural Assemblies during S-Lay Installation

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Abstract: The first paper in this series introduced a dual classification framework for subsea pipeline inline hardware — a physical taxonomy describing how hardware joins the pipeline string (IW/EA) and a mechanical taxonomy describing how it amplifies strain during stinger passage (Types A, B and C) — and characterized the behaviour of inline welded components, which are cut into the string and act over a short length. This second paper turns to a different and far less studied class of hardware: complete structural assemblies mounted onto the pipeline. Top Structures (EA-ST) and Base Structures (EA-SB) are not welded into the string; they are built around the pipeline, span twenty pipe diameters or more, and transfer load into it at a small number of discrete attachment points. Their behaviour during stinger overbend passage has not previously been characterized in the open literature, and it cannot be inferred from inline component results, because the governing parameters are different.

Industry practice for top structures, base structures, mudmats and branch piping is first surveyed and reduced to a taxonomy suitable for automated design, including a unified classification of the connection systems through which a structure is attached to the pipeline: fixed at one point, fixed at two points, pin-slot, and variants of each incorporating a deadband gap (F1, F2, PS and their D variants). Parametric Abaqus finite element analyses incorporating stinger–pipeline contact are then used to characterize the resulting strain behaviour, extending the mechanical taxonomy of the first paper from effects distributed along a component to effects concentrated at discrete attachment points. Added mass is treated as an independent design variable, decoupled from stiffness, and branch piping support layout is examined as the canonical worked example of concentrated stiffness transfer. Key findings include: the attachment layout, not the size or weight of the structure, governs the strain imposed on the pipeline; a top structure attached at a single point, or through a pin-slot pair, leaves the pipeline close to its plain-pipe strain, while a rigid two-point attachment concentrates high strain at those points and creates a low-strain zone between them suitable for housing strain-sensitive equipment; the same pin-slot arrangement is markedly less effective on a base structure, showing that connection behaviour does not transfer directly between structure types and must be assessed against the structure geometry; deadband connectors redistribute strain along the pipeline rather than reducing it, so gap control governs the outcome; branch piping strain and header pipeline strain are governed by two largely independent levers that can be optimized separately; and added mass follows the same position-governs principle as stiffness and elevation. Together with the first paper, these results complete the design intuition layer of the proposed AI-assisted conceptual engineering programme for the full inline hardware set.

Keywords: S-lay installation; AI based Subsea ILT design; S-Lay ILT in Overbend; AI in Subsea Engineering, Subsea Structure Design; AI Framework for Structural concept development;

I. INTRODUCTION

A. Context: The AI-Assisted Conceptual Engineering Programme

This paper is the second in a series developing an AI-assisted conceptual engineering framework for structural design, using the S-Lay Inline Tee (ILT) design problem as the working case study. The first paper [1] introduced the programme's seven-step structure (Refer TABLE I), established a dual classification of inline hardware — the physical IW/EA taxonomy describing how hardware connects to the pipeline string, and the mechanical Type A/B/C taxonomy describing the strain-amplification mechanism each

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connection produces during stinger passage — and characterized the distributed-parameter behaviour types A1 (uniformly distributed stiffness), B1 (uniform elevation) and C1 (their combination). The reader is referred to [1] for the full literature review, the code framework governing inline component design (DNV-ST-F101 and ASME VIII), and the Abaqus modelling methodology; these are summarized only briefly here in Sections I.C and VI.

TABLE I. SEVEN-STEP AI-ASSISTED CONCEPTUAL ENGINEERING DEVELOPMENT PROGRAMME

Step	Capability	Objective	Scope
1	Component Taxonomoy	Identify the fundamental components of the assembly and classify them with ID tags for consistent identification	Ref [1]
2	Design Intuition	Characterise strain amplification mechanisms for each IW/EA component type as a function of geometry, length, elevation offset and attachment stiffness. Components can be classified into two groups as below	Ref [1]
		Type A1, B1 and C1: Applicable for IW-P, IW-A, EA-O	
		Type A2, B2 and C2: Applicable for EA-SB, EA-ST, IW-B	**This Paper**
3	Intuitive Assembly	Predict dominant mechanical behaviour(s) type (A, B, or C) for a given assembly configuration before analysis. Translate component-level intuition into assembly-level design judgement.	Future Work
4	Simplified Analysis	Develop reduced-order models for rapid parametric sensitivity screening without full Abaqus execution. Enable AI-driven iteration at concept stage.	Future Work
5	Design Code Assessment	Automate DNV-ST-F101 and ASME VIII capacity checks against computed demands. Integrate code compliance as a primary concept filter.	Future Work
6	Iterative Analysis	Closed-loop automated parametric workflow combining simplified models, code checks, and structured result interpretation with minimal manual intervention.	Future Work
7	Configuration Optimization	Identify governing parameters and systematically adjust toward minimum peak strain configurations within applicable code limits.	Future Work

The hardware studied in [1] was inline welded (IW) hardware (i.e. the pipeline is cut, the component is welded into the string, and it becomes part of the pressure boundary) and externally attached (EA) hardware that imposes elevation without stiffness addition (eg: shrouds). Such components have relatively simple mechanical effects on the Pipeline strain behaviour in overbend. The Top and Base Structures considered here have more complex behavior patterns, however the scope studied in [1] could provide some preliminary insights into current scope as well.

The present paper addresses hardware that is most commonly used in S-lay ILTs. An ILT is not simply a thick component in the line — it is a complete structural assembly built around the pipeline. A Top Structure sits over the pipeline and carries the branch piping and connector. A Base Structure (if required) runs beneath it, contacts the vessel rollers, and later distributes load to the seabed. Neither is welded into the string. Both are attached to the pipeline at a small number of discrete points, and both span a considerable length of pipe, typically ten to thirty diameters.

For an inline component, the mechanical behaviour driven by wall thickness, length and offset depth. For a mounted structure, those parameters are not directly relevant to the pipeline: what governs is how many attachment points there are, where they sit, what each one permits or restrains, and how stiff the structure is between them. A structure can therefore be large and heavy and still impose almost no strain penalty, or be modest in size and impose a severe one, depending entirely on its attachment layout. That result is not obtainable from inline component data, which is why these structures need to be characterized on their own terms.

B. Scope and Contributions

Structural assemblies of this kind are used on essentially every subsea inline tee and inline structure installed by S-Lay, yet their mechanical behaviour during stinger overbend passage does not appear to have been characterized in the open literature. Design practice relies on project-specific analysis and on engineering judgement carried between projects. To the authors' knowledge this paper is the first systematic parametric treatment of Top Structure and Base Structure behaviour during S-Lay overbend passage. That is its principal contribution.

The paper makes four contributions.

1) First, it surveys the structural assemblies and branch piping configurations used in practice for subsea ILT structures, and identifies the individual modules — Top Structure, Base Structure, mudmat, branch piping — and the ways they are joined to one another and to the pipeline.

2) Second, it introduces a taxonomy suitable for automated design processes, covering both the structural components themselves and the connection systems through which they attach to the pipeline (F1, F2, PS and their Deadband variants), together with a schematic drawing convention that allows an assembly to be plotted programmatically rather than described in prose.

3) Third, it characterizes the mechanical behaviour of these assemblies through parametric finite element analysis, and classifies that behaviour into the concentrated-parameter types A2, B2 and C2 that [1] scoped as future work.

4) Fourth, it treats two effects not addressed in the distributed study: added mass as an independent design variable, decoupled from stiffness; and branch piping (IW-B) support layout, examined as the canonical worked example of Type A2 behaviour, since the branch connects rigidly to the header at the Tee and transfers concentrated stiffness and mass to the pipeline through its support arrangement

Together with [1], these results complete Steps 1 and 2 of the seven-step development programme — Component Classification and Design Intuition — for the full IW/EA hardware set. Refer to Figure 1 for the conceptual design framework and the scope of this paper.

Scope boundary

One boundary should be stated at the outset. Where a structure is attached to the pipeline, an anchoring component (IW-A, typically a bulkhead with a welded boss) is normally present at the attachment point. Such components are inline welded hardware and are short, so their effect on pipeline strain is local and falls within the Type A1 behaviour already characterized in [1]. They are not modelled here.

This is a deliberate choice: the aim of this paper is to characterize the behaviour of the structure itself, which is the dominant part of the assembly by length and by mass, and including the anchoring components would confound the structural effect with an effect already known.

In a full design assessment the local IW-A contribution from [1] is superimposed at each attachment point. Reported strains are therefore intended for relative comparison between structural arrangements, not as absolute values for code compliance.

C. Physical and Mechanical Classification of Inline Hardware — A Recap

This section briefly recaps the classification and taxonomy proposed in [1], which the present paper builds on.

Hardware was classified on two independent axes: its physical assembly characteristics, and its mechanical behaviour during overbend passage.

The physical axis separates inline welded hardware (IW), which is cut into the string, from externally attached hardware (EA), which is not. The structures studied in this paper fall in the EA group, specifically the built-up structural sub-group EA-S. Refer TABLE II for the physical classification of inline hardware.

The mechanical axis describes what a piece of hardware does to the pipeline strain field. Type A is stiffness-dominant, Type B is elevation-dominant, and Type C combines the two. Each divides into a distributed form, in which the effect acts continuously along the hardware's own length, and a concentrated form, in which it acts only at discrete points. The distributed forms A1, B1 and C1 were characterized in [1].

The concentrated forms A2, B2 and C2 are the subject of this paper, and they arise naturally from mounted structures, because a mounted structure can only reach the pipeline at the points where it is attached. Refer to TABLE III for the mechanical behaviour classification.

TABLE II . PHYSICAL CLASSIFICATION OF INLINE HARDWARE (IW / EA NOMENCLATURE)

Group Code	Connection Method	Description	Item Code	Connection to Pipeline
IW (Inline Welded)	Full-penetration girth butt weld (with tapered NIB) at each end. Pipeline is cut; component becomes part of the string.	Piping Components (Valve, Flange, TEE etc)	IW-P	Full-penetration girth butt weld inline into string. Large OD requires EA-O or EA-SB for roller management.
		Anchoring Components	IW-A	Welded inline. Provides the connection point for EA-SB/ST. Large OD (eg: PIP bulkhead) requires EA-O or EA-SB for roller management.
		Branch Piping	IW-B : IW-BL IW-BZ	IW-BL : L Shaped branch typically used with Horizontal Connectors IW-BZ : Z Shaped branch typically used with Vertical Connectors
EA (Externally Attached)	Externally attached built up Structure – Frame or Shell (EA-S)	Base Structure	EA-SB	Connected to pipeline at 1 or more locations via IW-A or EA-R. Runs below pipeline and below inline piping components.
		Top Structure	EA-ST	Connected to pipeline at 1 or more locations via IW-A Boss or EA-R. Runs on top of the pipeline, usually cover the piping components
	Other Externally attached component	EA — Ring	EA-R	Sleeve pipe with encircling fillet girth weld to pipeline OD. Provides connection point for EA-S when no IW-A is present.
		EA — Offset Element (Shroud)	EA-O	No structural weld-line connection. Geometric contact only Used to provide an alternative contact surface with rollers, usually to elevate and control pipeline curvature

TABLE III . MECHANICAL BEHAVIOUR CLASSIFICATION (TYPES A–C) FOR OVERBEND STRAIN ANALYSIS.

Type	Name	Stiffness Effect	Elevation Effect	Description
A (A1/A2)	Stiffness-dominant	Significant	Minor	Broadly classified into 2 Sub types o A1: Uniformly distributed stiffness (eg: thick component) (Scope of [1]) o A2: Stiffness concentrated at connection points (eg: EA-ST or IW-B rigidly connected to pipeline at distinct points) without adding elevation ● Scope of this paper
B (B1/B2)	Elevation-dominant	Minor	Significant	Broadly classified into 2 Sub types o B1: Component applies elevation to pipeline directly above it without restricting bending (eg: Shroud) (Scope of [1] o B2: Component applies elevation at distinct points where its attached, without restricting bending (eg: some EA-SB) ● Scope of this paper
C	Combined	Variable	Variable	Broadly classified into 2 Sub types o C1: Combination of A1 and B1 o C2: Any other combinations between A and B, adding Stiffness and/or Elevation to Pipeline ● Scope of this paper

Summary of the behaviour type studies covered in this paper is presented in TABLE IV

TABLE IV . SCOPE OF THE PRESENT PAPER — CONCENTRATED-PARAMETER BEHAVIOUR TYPES

Item Studied	Studied Via
Type **A2** Mechanical Behaviour	Top Structure with bending restraining connections to Pipeline
Type **B2** Mechanical Behaviour	Base Structure with flexible connections to Pipeline
Type **C2** Mechanical Behaviour	Various combinations of Stiff and flexible connections between Pipeline and Base Structure
Mass Distribution effect	Point-mass (Inertia) elements, distributed at various spacings
Branch Piping (**IW-B**) Mechanical Behaviour	Different branch piping layouts and its connections so the Top Structure and Pipeline. Branch types are classified as **L** and **Z** types

D. Nomenclature Table

TABLE V . NOMENCLATURE TABLE

Symbol	Meaning
P_c1	Distance between the two interior connection points of a structure
P_c2	Distance from an interior connection point to the deadband connection at the end
P_l1, P_l2	Base Structure length: flat centre length and sloped end length
P_v	Vertical depth pf the Base Structure
P_vt (for EA-SB)	Vertical offset from the pipeline to the top side of Base Structure
P_vt (for EA-ST)	Vertical offset from the pipeline to the underside of Top Structure
P_gap	Gap in a deadband (D) connector before load transfer starts
P_b1, P_b2	Branch pipe horizontal run and vertical rise
P_bc	Distance from the Tee to the nearest structure connection point
kT, kT1, kT2	Top Structure bending stiffness between connection points, as a multiple of pipeline stiffness
kB, kB1, kB2	Base Structure bending stiffness between connection points, as a multiple of pipeline stiffness
X_c	Pipeline region near a connector, 2 x pipe OD on each side
X_i, X_i2	Pipeline regions inside the structure
X_e	Pipeline region outside the structure

II. TYPICAL ILT ASSEMBLIES

A. General

Before the behaviour of a complete assembly can be studied, the parts that make it up and the ways they interact need to be identified. This section summarizes industry practice under three headings:

- Components — welded frame and plated structures, together with the other externally attached (EA-S) structural elements used alongside them.
- Connectors — the load transfer interfaces between the individual structural components classified above.
- Connection systems — assemblies of several connectors arranged to achieve a particular load transfer behaviour between components.

The order matters. The components define what the assembly is; the connectors and connection systems define how load reaches the pipeline, and therefore how the assembly behaves during overbend passage. The behaviour studies in Sections VII and VIII vary the connection arrangement precisely because it is the parameter that changes the structural effect, while the structure itself remains the object of study.

B. Components

Structural components used in ILT structures fall into two broad groups based on mechanical and functional behaviour:

- Top Structure (EA-ST), which occupies the region above the pipeline, covers the inline piping components, and provides support and anchoring interfaces for the branch piping. Refer to Fig. 1 and Fig. 2.
- Base Structure (EA-SB), which covers the underside of the pipeline and the inline components, contacts the vessel rollers during installation, and may contact the seabed or mudmat after installation. Refer to Fig. 3.

Many sub-types exist in practice, but this two-way grouping captures the mechanical distinction that matters during overbend passage. A Top Structure is attached above the pipeline and does not normally contact the rollers, so it acts on the pipeline only through its attachment points. A Base Structure sits below the pipeline and does contact the rollers, so it can carry roller load directly and lift the pipeline away from the roller line. This is the reason the two behave differently under nominally identical connection arrangements, as Sections VII and VIII demonstrate.

Almost all ILT structures also include a mudmat (refer to Fig. 4, Fig. 5), whose purpose is to distribute load to the seabed once installed. Mudmats are rarely attached directly to the pipeline, so they are not classified separately in the taxonomy or the behaviour grouping. A mudmat may be connected to the Base Structure, connected to the Top Structure, or installed independently; where it is attached, its mass and stiffness are combined into whichever structure carries it.

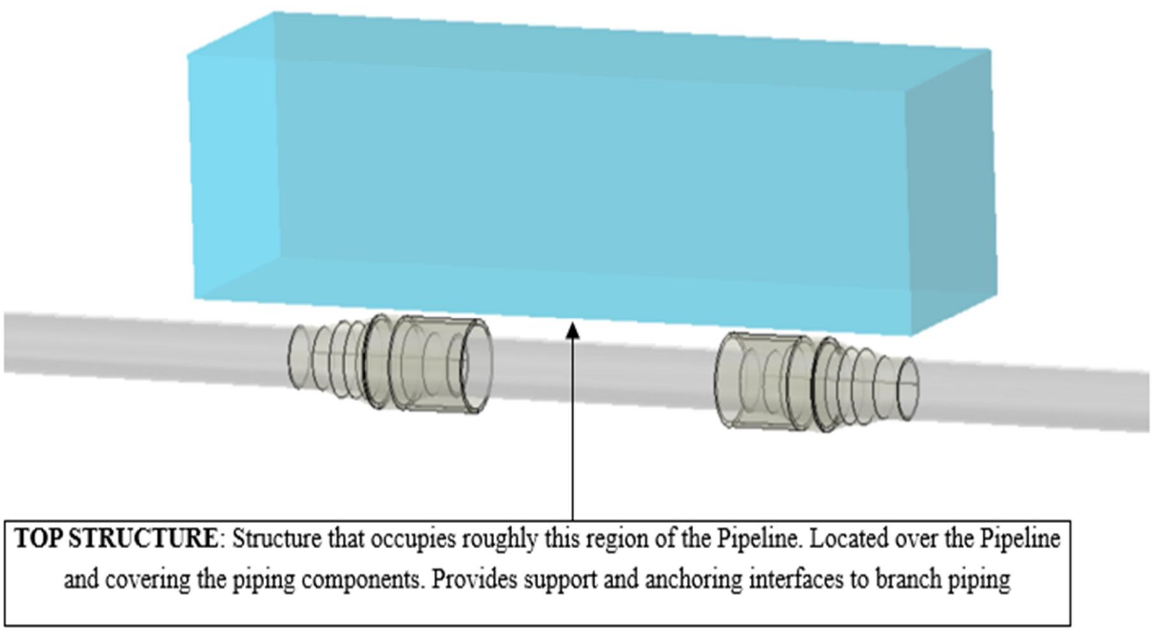

Fig. 1. Top Structure - Schematic Representation (Isometric view)

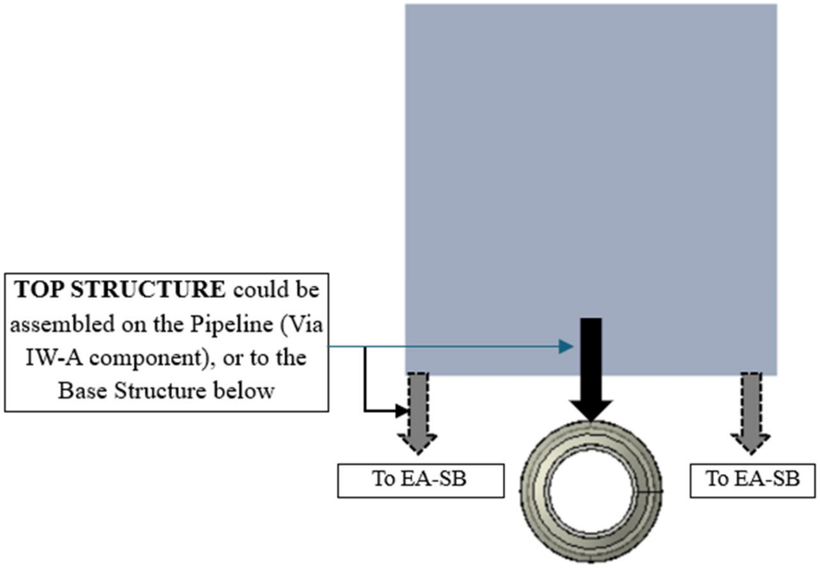

Fig. 2. Top Structure - Schematic Representation (End View)

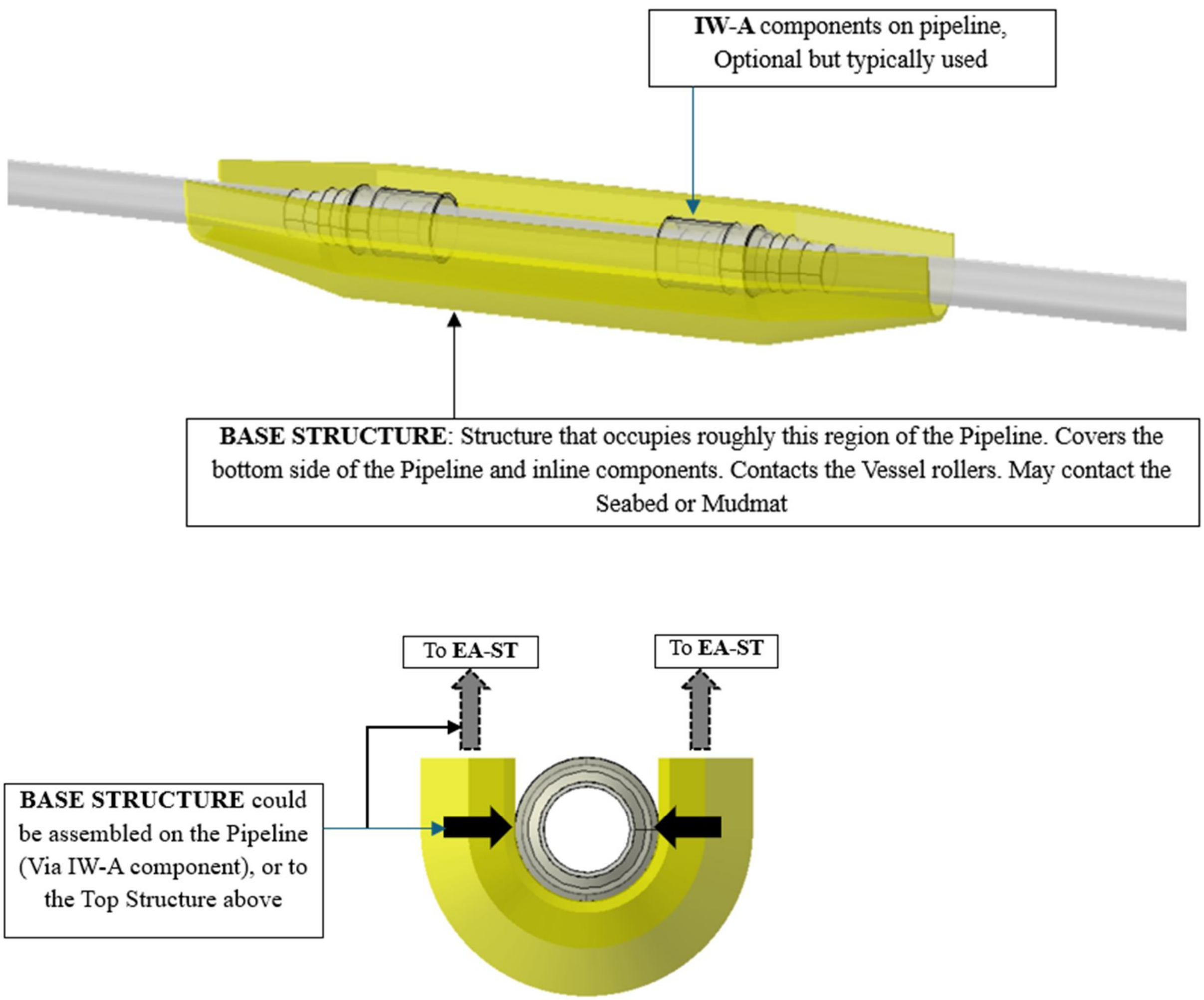

Fig. 3. Base Structure - Schematic Representation

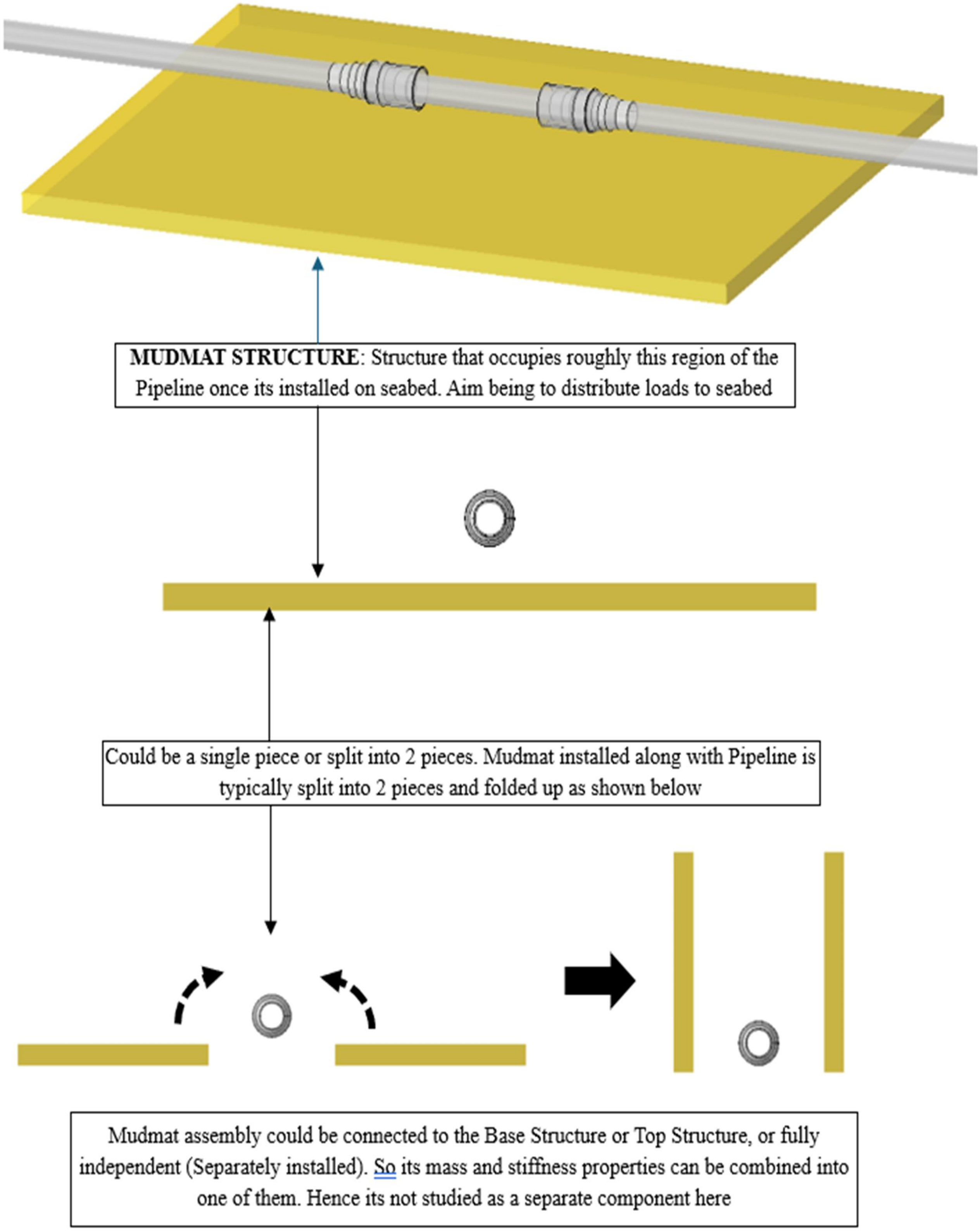

Fig. 4. Mudmat - Schematic Representation

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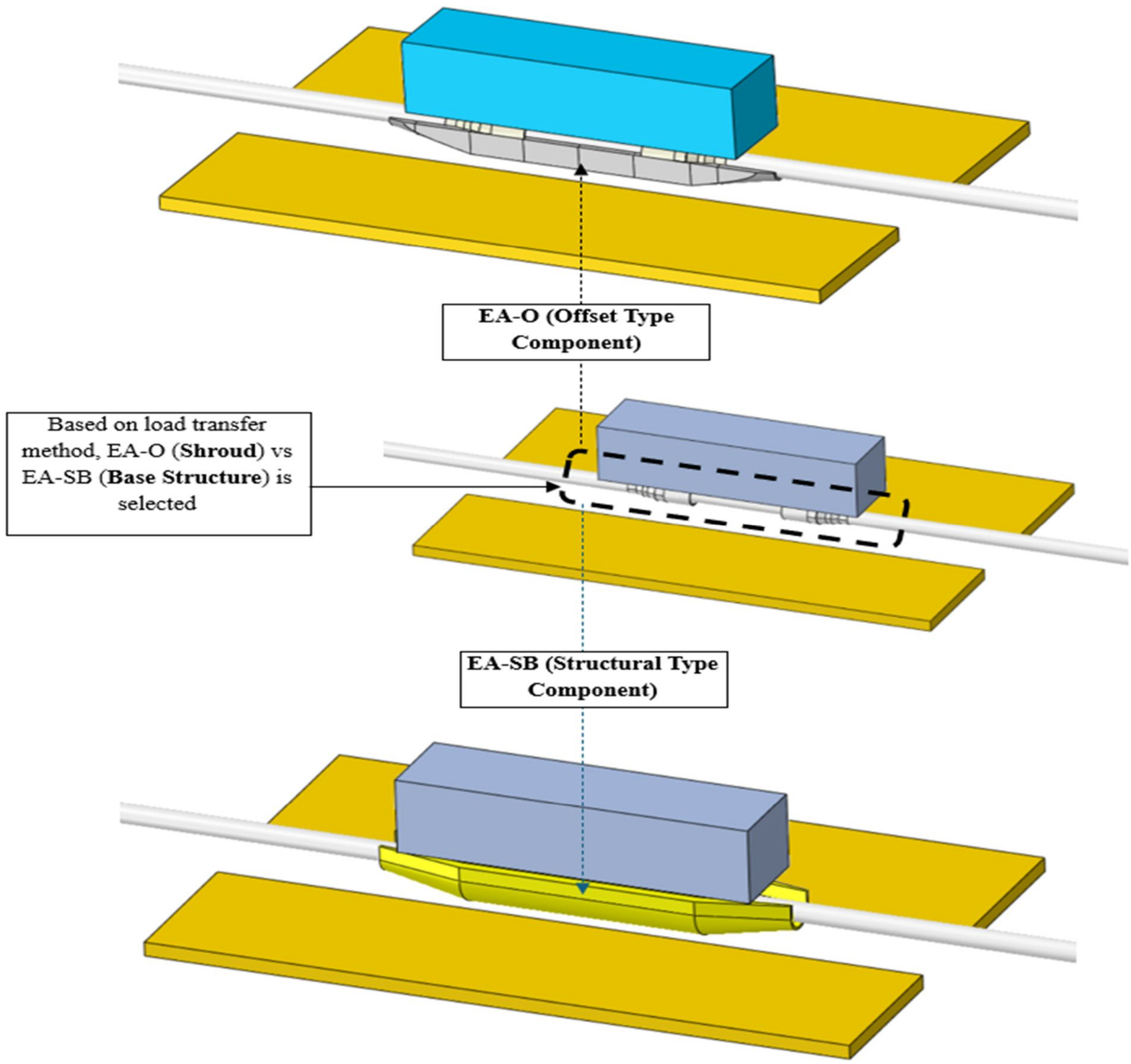

Fig. 5. Overall Assembly - Schematic Representation

C. Assembly of Structures

The components described above can be assembled in several ways. The main principles and examples are as follows.

- One **EA-S** component — either the Top Structure or the Base Structure — is connected directly to the pipeline.
- A second **EA-S** component, where required, is connected to the first (for example **EA-SB** connected to **EA-ST**, or the reverse).
- The mudmat is assembled onto either **EA-S** component.
- Connections between individual structural components may be rigid or flexible, depending on the design concept.
- The Top Structure may itself be split into two parts: one attached to the pipeline (**EA-ST1**) and one attached to the mudmat (**EA-ST2**), with a sliding interface between them that allows the pipeline and **EA-ST1** to move relative to the mudmat. Refer to Fig. 6.
- Similarly, the Base Structure and mudmat may be attached to the Top Structure through sliding connections, with the Top Structure connected to the pipeline. Refer to Fig. 7.

The sliding arrangements in the last two cases exist because the pipeline stretches and moves relative to the assembly during operation. They are a good illustration of why connection arrangement cannot be treated as a detail: the same set of structural components, assembled with different interfaces, produces a different load path into the pipeline and therefore a different strain response.

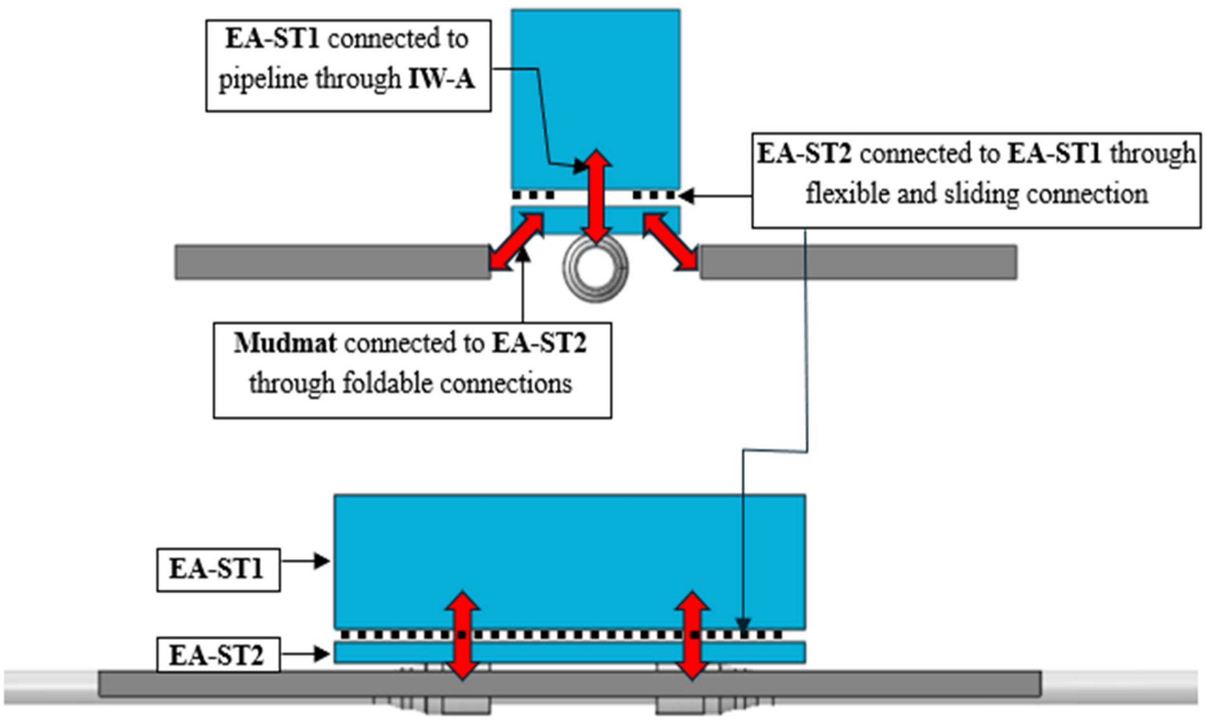

Fig. 6.Example 1 - Structural Assembly to suit Pipeline sliding

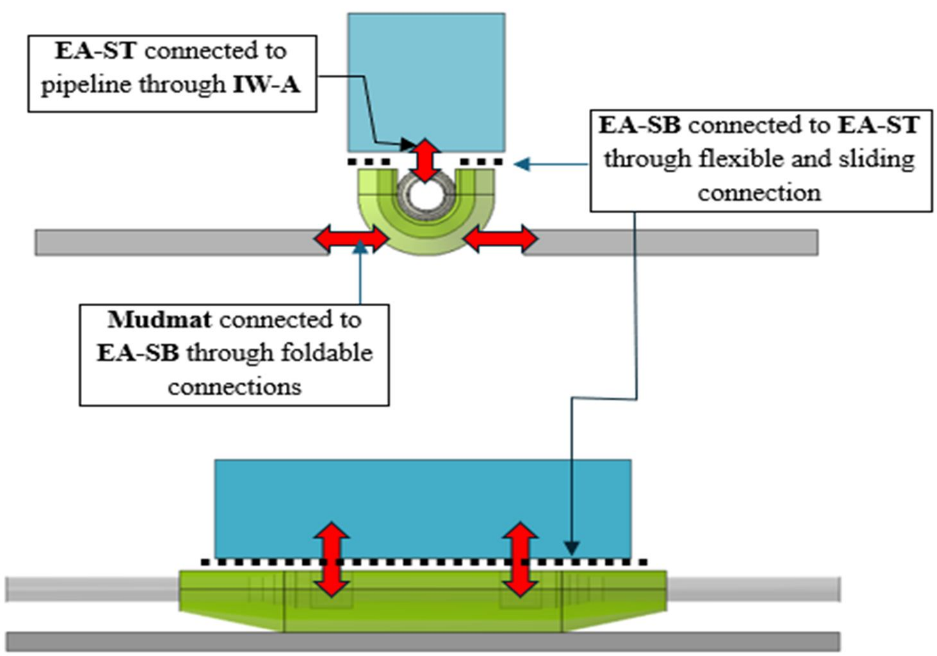

Fig. 7. Example 2 - Structural Assembly to suit Pipeline sliding

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D. Connectors and Connection Systems

Structural components (EA-S) could be connected to Pipelines by several methods. The most robust and practiced method is to have a weldable or boltable interface on a IW-A component. A Structural element is welded or bolted on this interface. Then the primary structural framing or plating of the EA-S component is welded to this interface element. Following typical piping convention, this interface structural element has been referred to as ‘BOSS’ in this document. Some examples of common industry practices are presented in below figures. Note that the details are representative. Actual structural details will be slightly different.

- Refer Fig. 8 for common types of IW-A (Bulkhead) incorporation in pipeline.
- Refer Fig. 9 for examples of rigid assembly of Base Structure on Pipeline. Structural Boss pipe is welded on a PIP bulkhead and the Base Structure is welded to the Bosses.
- Fig. 10 presents examples of rigid connection between Top Structure and Pipeline through PIP bulkheads.
- Fig. 11 presents examples of direct rigid connection of Base Structure to PIP Bulkheads
- Fig. 12 and Fig. 13 presents examples of Flexible connection between Top/Base Structure and Bulkheads. Shows how Sleeved Structural elements are required for this type of Assembly, and how they could be used.
- Fig. 14 shows how combinations of connection types are used in an assembly. Deadband connection refers to a connection which has a gap, and the connection becomes active after the gap is closed after some pipeline deformation.
- Fig. 15 presents the common types of Branch layout.

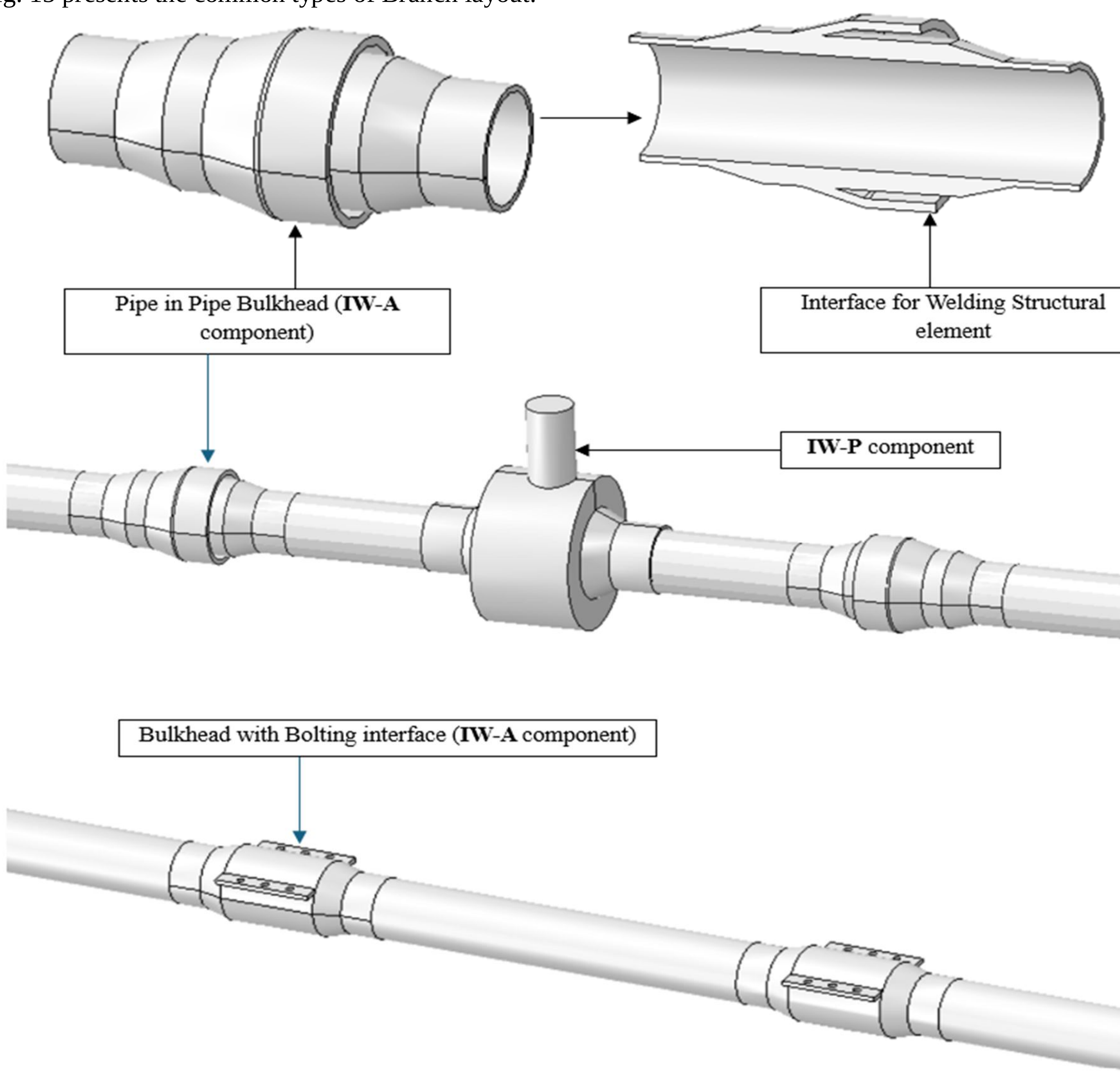

Fig. 8. Examples - Bulkhead integration in Pipeline

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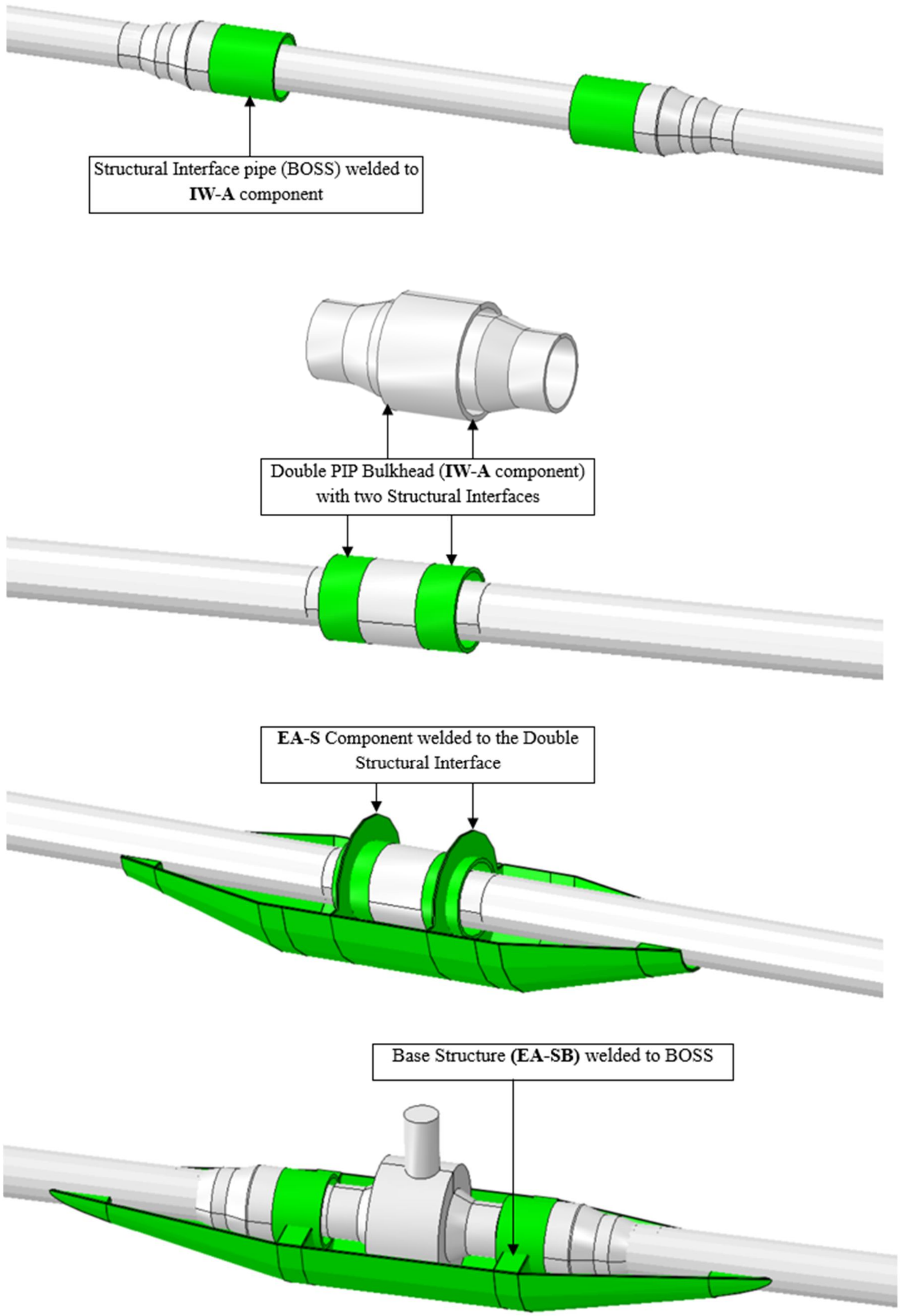

Fig. 9. Examples - Rigid Connection of Base Structure to Bulkheads via BOSS elements

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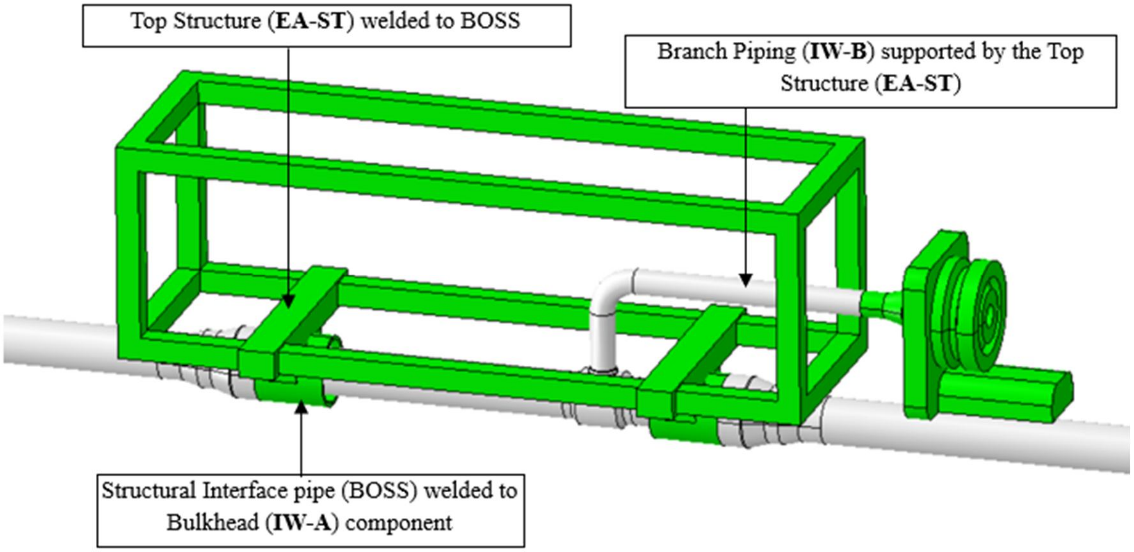

Fig. 10. Example - Rigid Connection of Top Structure to Bulkheads via BOSS elements

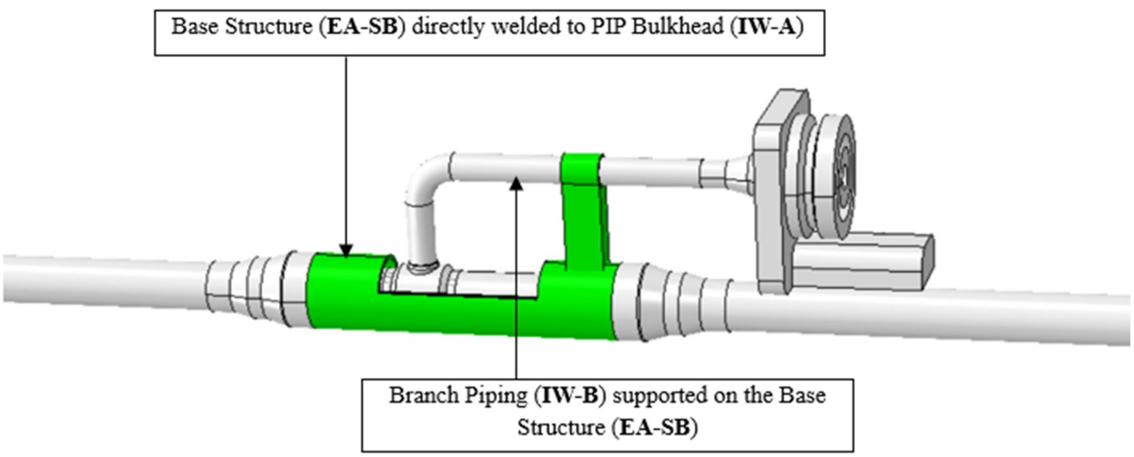

Fig. 11. Example - Direct Rigid Connection of Base Structure to Bulkheads

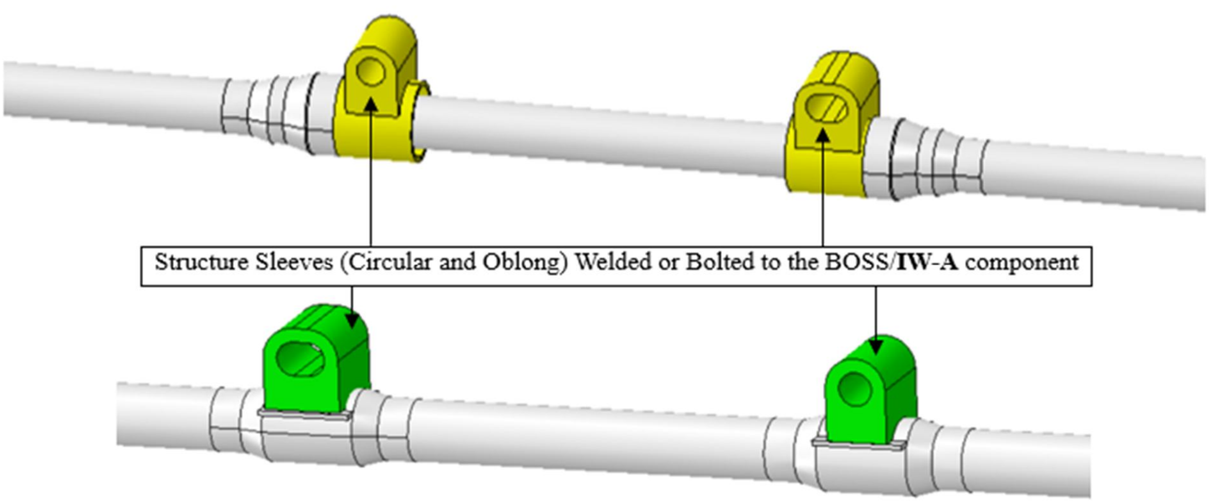

Fig. 12. Examples - Structural Sleeve Incorporation in Pipeline

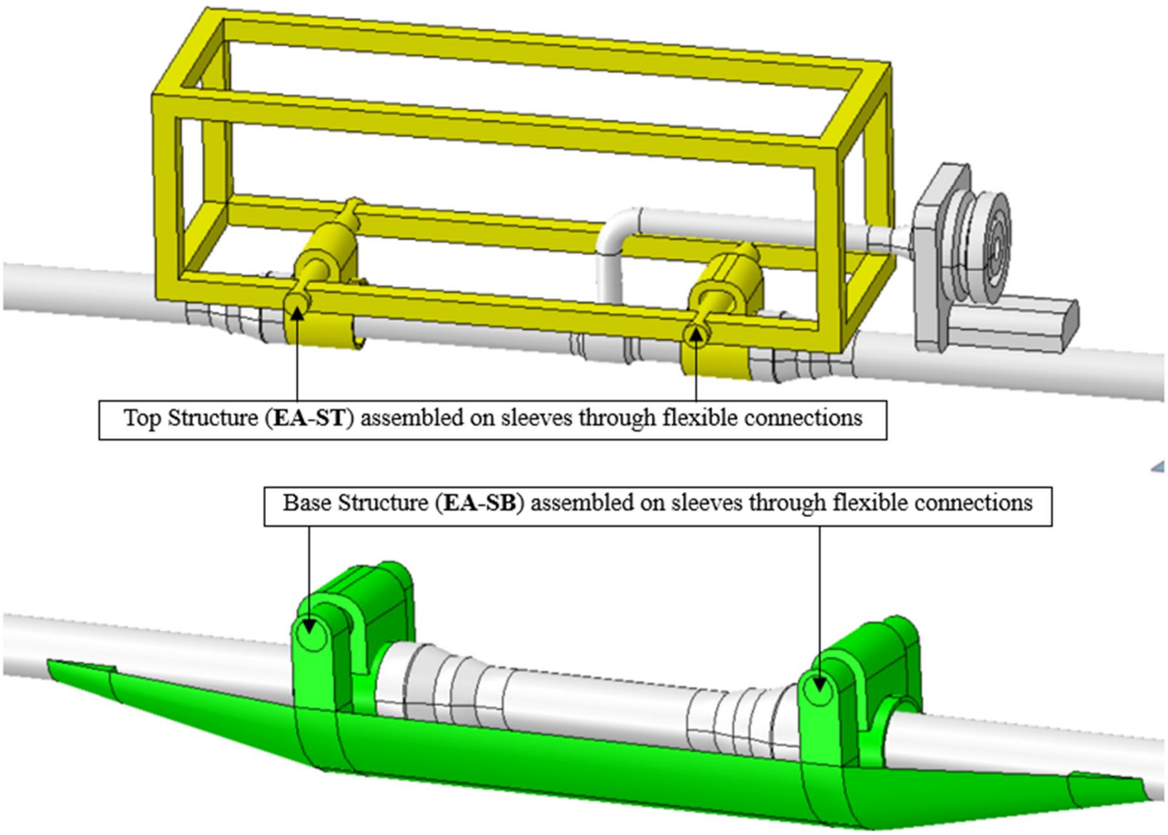

Fig. 13. Examples - Flexible Connection of Top Structure and Base Structure to Bulkheads

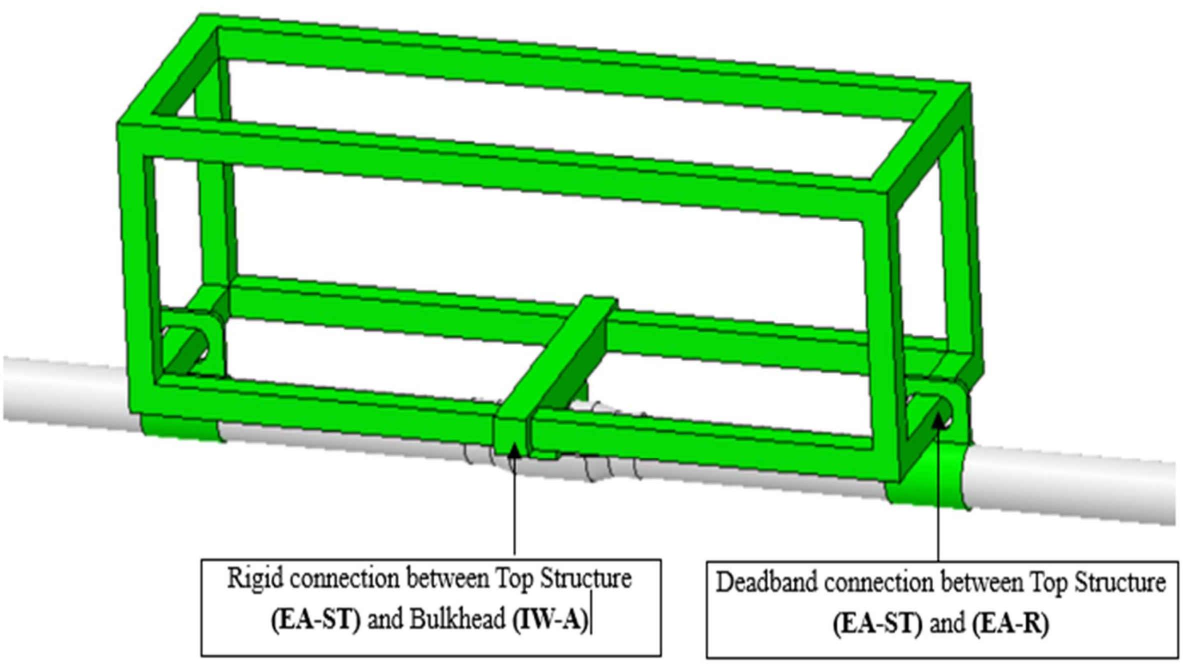

Fig. 14. Example - Combination of connection types between EA-S and Bulkhead

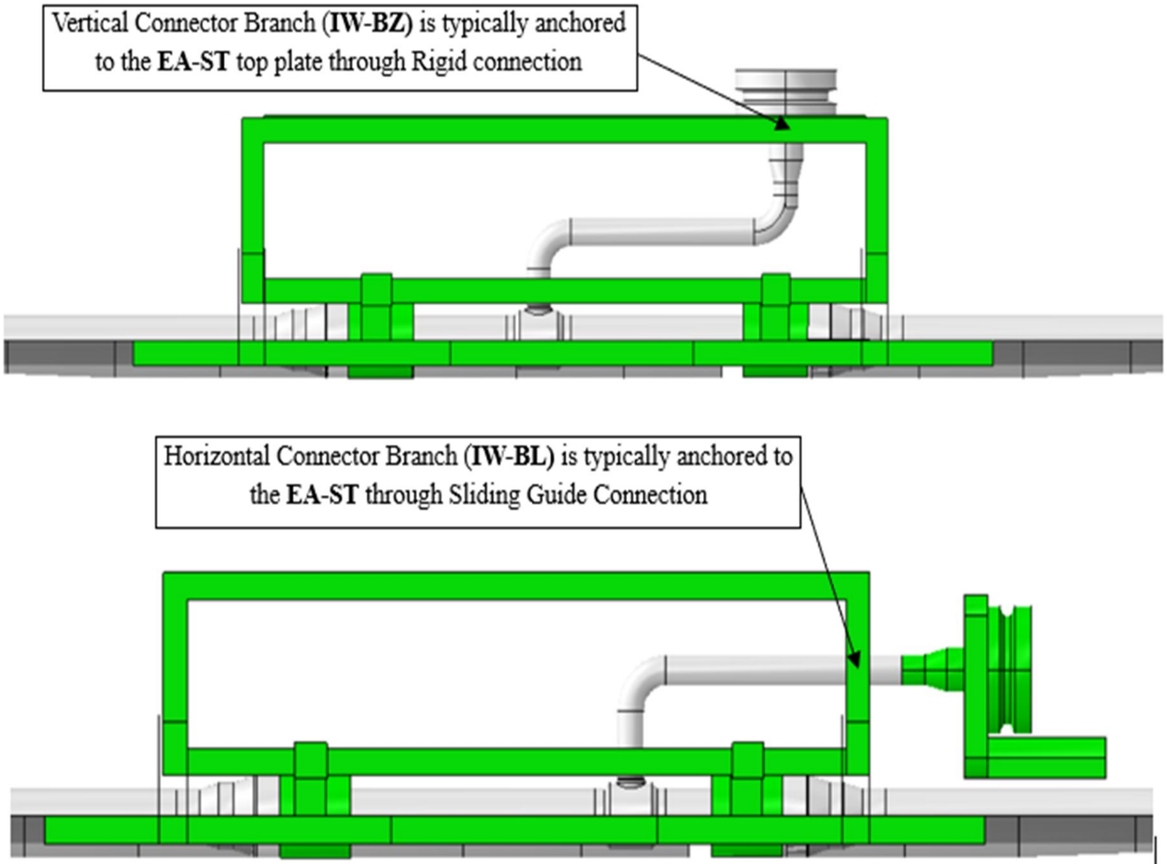

Fig. 15. Example - Common types of Branch Layout

III. TAXONOMY FOR COMPONENTS AND CONNECTIONS

A. General

The first step in a Structural assembly design is selection of components and connection methods appropriate for a given set of design requirements.

The second step would be to define them in terms of parameters. These parameters include those relevant for engineering (eg: dimensions affecting load transfer, mass, stiffness, restraints etc) and those relevant for design (eg: overall dimensions, shapes etc).

Therefore standardized Taxonomy along with Symbols are required for proper identification and Schematic preparation of the assemblies. Most of the component taxonomy is already discussed in previous sections. This section focuses more on Taxonomy for individual Connectors and Connection Systems.

B. Connector Taxonomy

As seen in the previous section, several connection methods are used between structures to pipeline in practice. There can be a single connection or multiple connections. Full connection assembly between two components can be put together with a few types of connectors.

Refer below for a few Connector types considered in this paper, based on prominent usage

- **F -** Fixed, connection where all DOF are connected
- **P -** Pinned, connection that allows only certain rotations
- **S -** Slotted, connection that allows linear sliding
- **D -** Deadband, connection that allows a specific amount of relative movement before activating load transfer

Refer Fig. 16 for more details and the Symbols considered in this document.

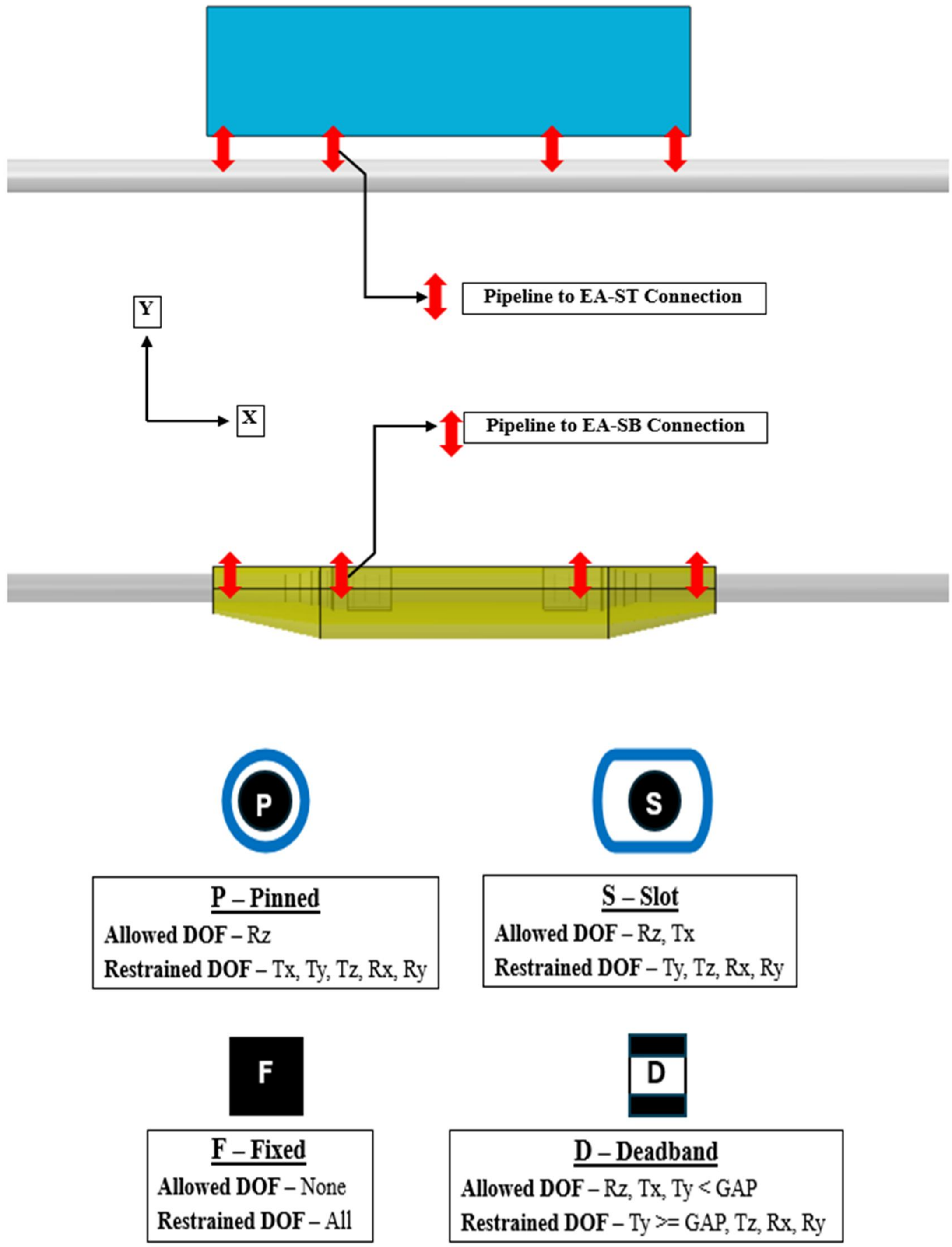

Fig. 16. Connector Taxonomy and Mechanical Properties

C. Connection Systems

As seen in the previous section, several connection methods are used between structures to pipeline in practice. There can be a single connection or multiple connections. Full connection assembly between two components can be put together with a few types of connectors. The most prominently used connection systems are considered here. Refer TABLE VI and Fig. 17, Fig. 18 for details of the proposed Taxonomy.

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Same Connection System Taxonomy is applicable for Top Structure as well as Base Structure

TABLE VI. CONNECTION SYSTEMS TAXONOMY

Code	Connection Arrangement	Remarks
F1	Fixed at 1 interior point (centre)	Refer Fig. 9
F1D	F1 + gap contacts at ends	Refer Fig. 14
F2	Fixed at 2 interior points	Refer Fig. 9, Fig. 10, Fig. 11
F2D	F2 + gap contacts at ends	
PS	Pin-slot at 2 interior points	Refer Fig. 13
PSD	PS + gap contacts at ends	

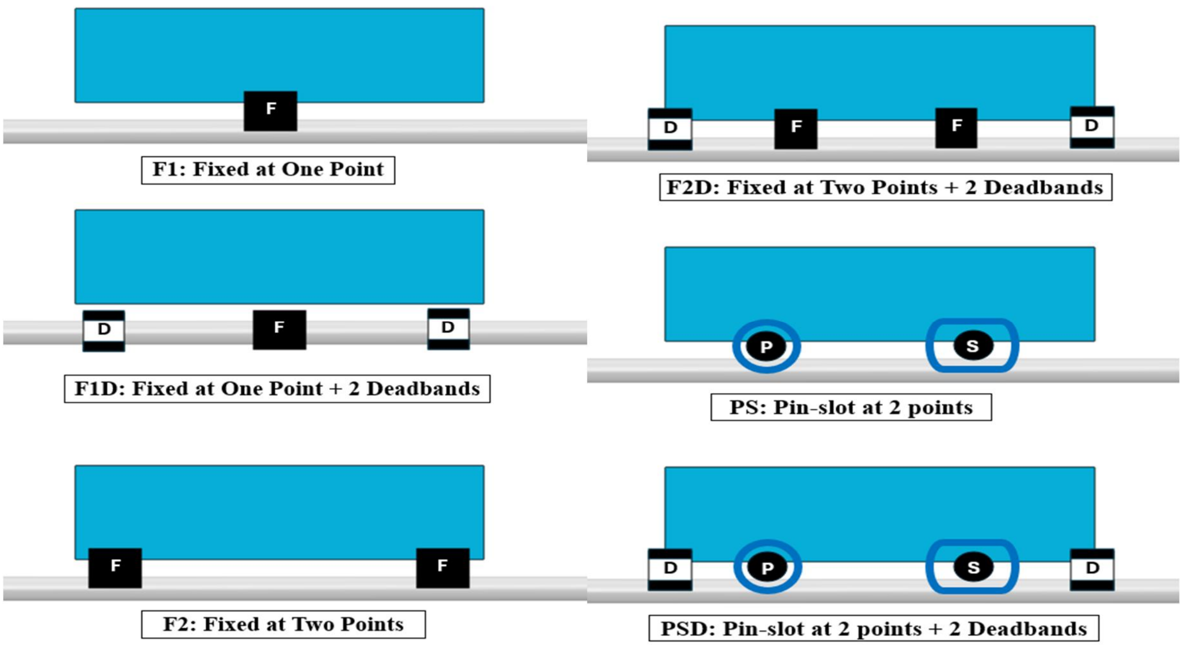

Fig. 17.Connection System Taxonomy - Top Structure Examples

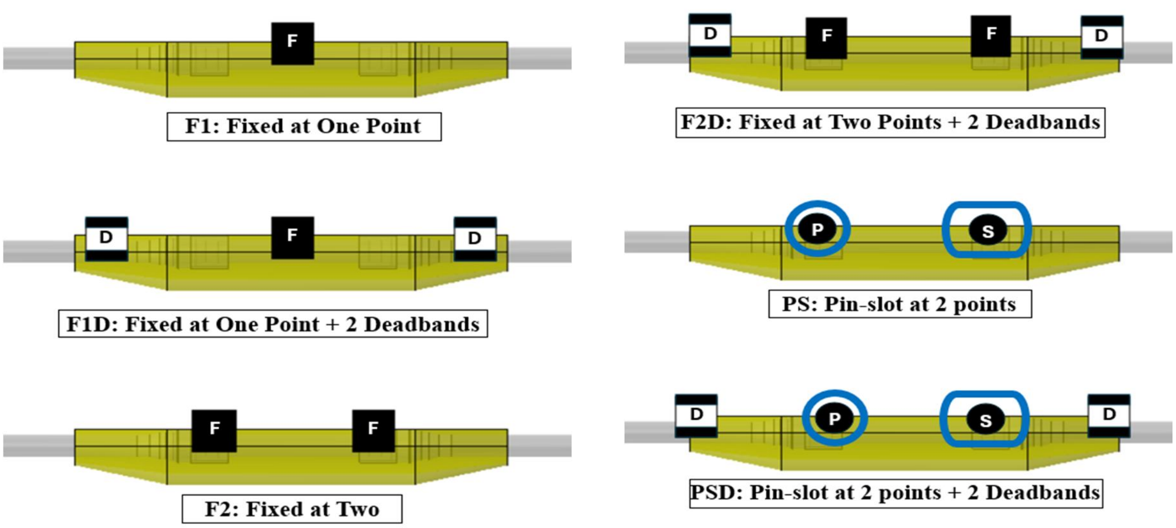

Fig. 18.Connection System Taxonomy - Base Structure Examples

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A. Schematic Drawings

For effective communication and AI based design, it is necessary to have a Schematic Drawing method which can be plotted in simple graphics, so that AI could use Python based tools to accurately plot the Structural assembly, including labels of the Components and Connections. This avoids hallucination errors typical for LLMs. Refer Fig. 19 for examples of how such a Schematic can be set-up.

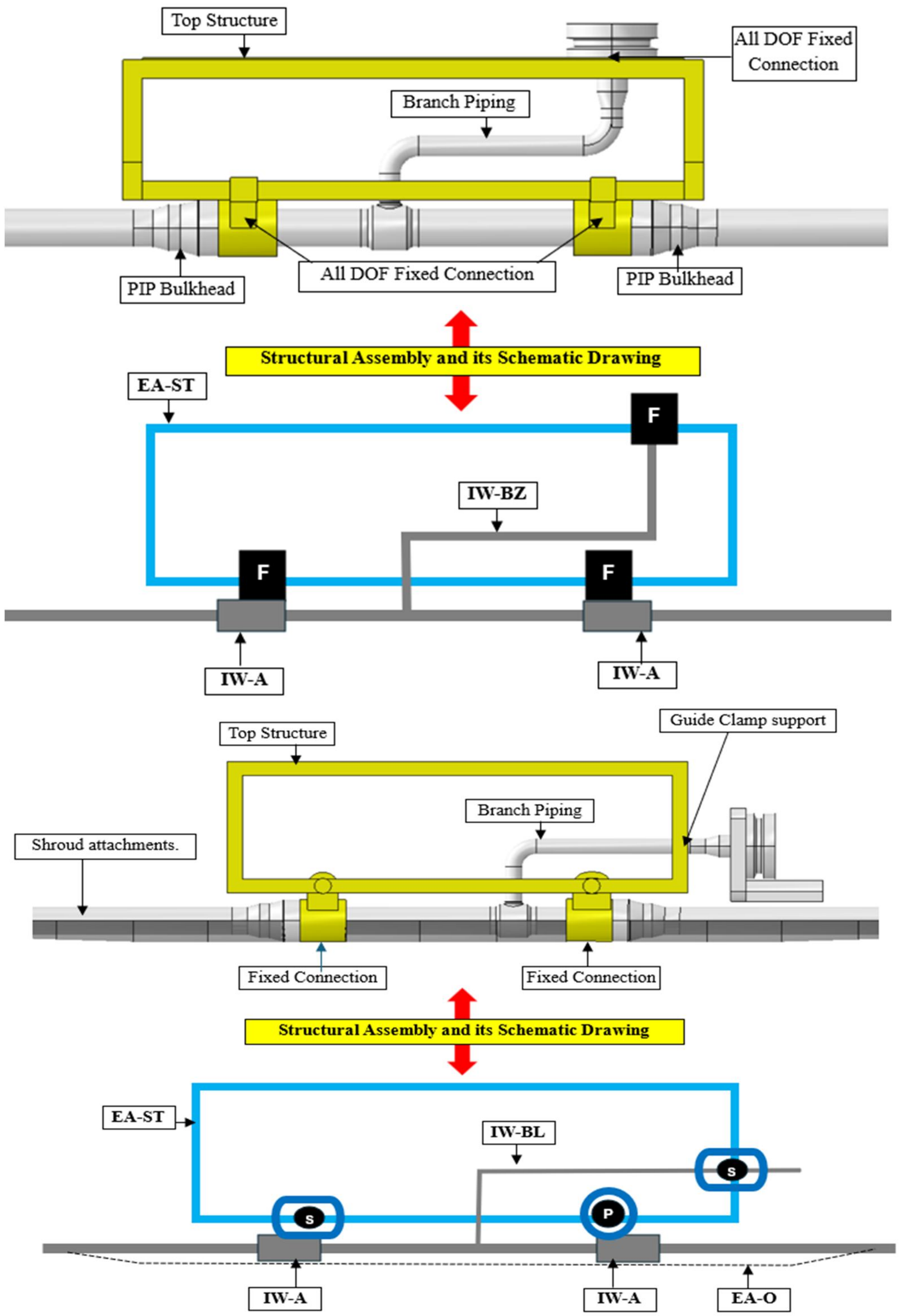

Fig. 19. Examples - Schematic Representation

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IV. TAXONOMY FOR BRANCH PIPING AND ITS SUPPORT ARRANGEMENT

A. General

Branch Piping is arguably the most important component inside the ILT Structure because the structure itself exists to connect an external jumper/spool to the main pipeline through the branch. Branch piping therefore ends with a connector in almost all cases. The method of restraining the branch pipe and connector affects the stress distribution within the branch piping as well as the header pipeline. Hence the branch piping and its support layout is provided its own dedicated classification and Taxonomy.

Since the same piping arrangement could have variable support arrangement, two layer Taxonomy is provided on the basis of

1. Piping layout
2. Support layout

Fig. 19 above shows types of branch piping based on its Geometry.

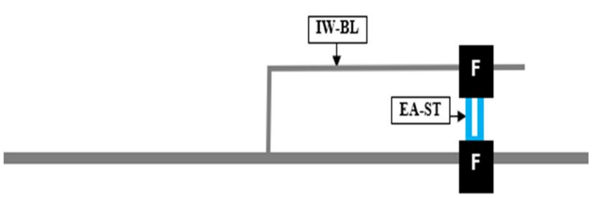
- IW-BL - For L-shaped branch pipe, typically used for Horizontal Connectors
- IW-BZ - For Z-shaped branch pipe, typically used for Vertical Connectors

For classification based on support arrangement, Refer
TABLE VII. Fig. 20 and Fig. 21 presents illustrative info.

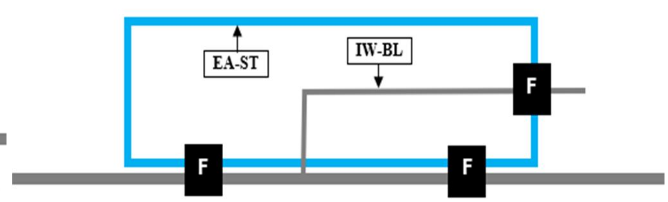
TABLE VII. BRANCH SUPPORT LAYOUT TAXONOMY

Code	Connection Arrangement	Remarks
L-FT-F1 / Z-FT-F1	Branch Pipe Fixed to Top Structure of Type F1	Refer Fig. 20 and Fig. 21
L-ST-F1 / Z-ST-F1	Branch Pipe Slot connected to Top Structure of Type F1	
L-FT-F2 / Z-FT-F2	Branch Pipe Fixed to Top Structure of Type F2	
L-ST-F2 / Z-ST-F2	Branch Pipe Slot connected to Top Structure of Type F2	
L-FT-PS / Z-FT-PS	Branch Pipe Fixed to connected to Top Structure of Type PS	
L-ST-PS / Z-ST-PS	Branch Pipe Slot connected to Top Structure of Type PS	
L-FT-PSD / Z-FT-PSD	Branch Pipe Fixed to Top Structure of Type PSD	
L-ST-PSD / Z-ST-PSD	Branch Pipe Slot connected to Top Structure of Type PSD	

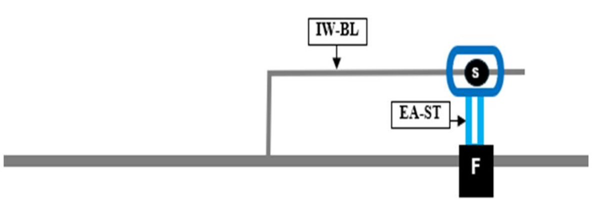
Note: Other connection types can be incorporated the same way. Taxonomy can be adjusted include more types



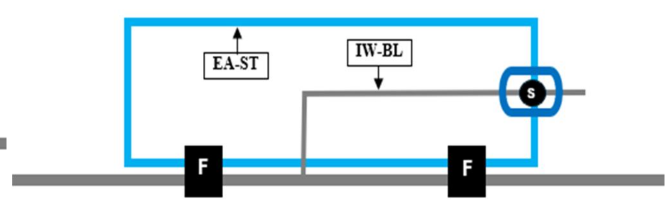
L-FT-F1: Branch with Fixed Support to EA-ST Type F1



L-FT-F2: Branch with Fixed Support to EA-ST Type F2



L-ST-F1: Branch with Slot Support to EA-ST Type F1



L-ST-F2: Branch with Slot Support to EA-ST Type F2

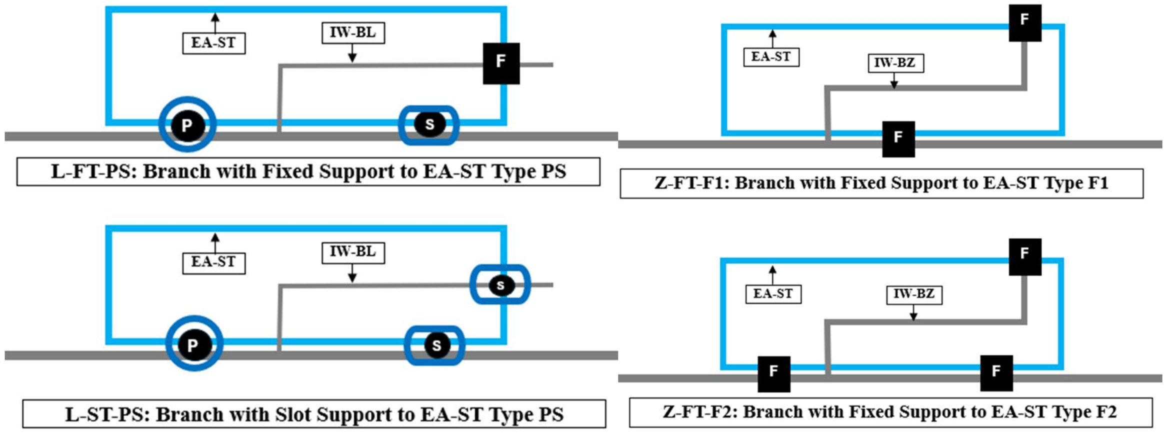


Fig. 20.Branch Piping Taxonomy Set 1 - Based on Support Layout

Note: EA-ST Type FD and F2D are not shown here, but applicable in design.

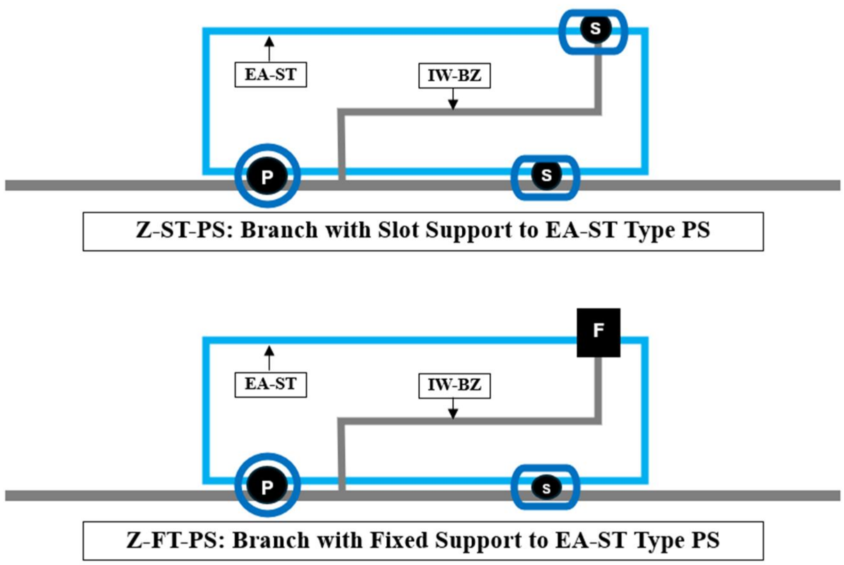


Fig. 21.Branch Piping Taxonomy Set 2 - Based on Support Layout

Note: EA-ST Type PSD is not shown here, but applicable in design.

V. COMPONENTS AND CONNECTORS - PARAMETRICAL REPRESENTATION

A. General

Parameters are characteristic details that can be used to define Mechanical and other details of Components and Connectors. Parameters can be classified as per below

- Engineering Parameters: Details relevant for engineering analyses , eg: Certain dimensions, stiffnesses etc
- Design Parameters: Details relevant for design modelling, eg: Geometrical details that does not affect engineering results

In this document focus will be on some of the Engineering parameters of the Components and Connections discussed in earlier sections. In practice, there could be more parameters, their effects can be studied in future works.

B. Top Structure (EA-ST) , Base Structure (EA-SB) and Branch Piping (IW-BL, IW-BZ) Parameters

Parameters considered for the EA-ST, EA-SB are shown in Fig. 22, Fig. 23 and TABLE VIII
Parameters considered for the IW-BL, IW-BZ are shown in Fig. 24, Fig. 25 and TABLE VIII

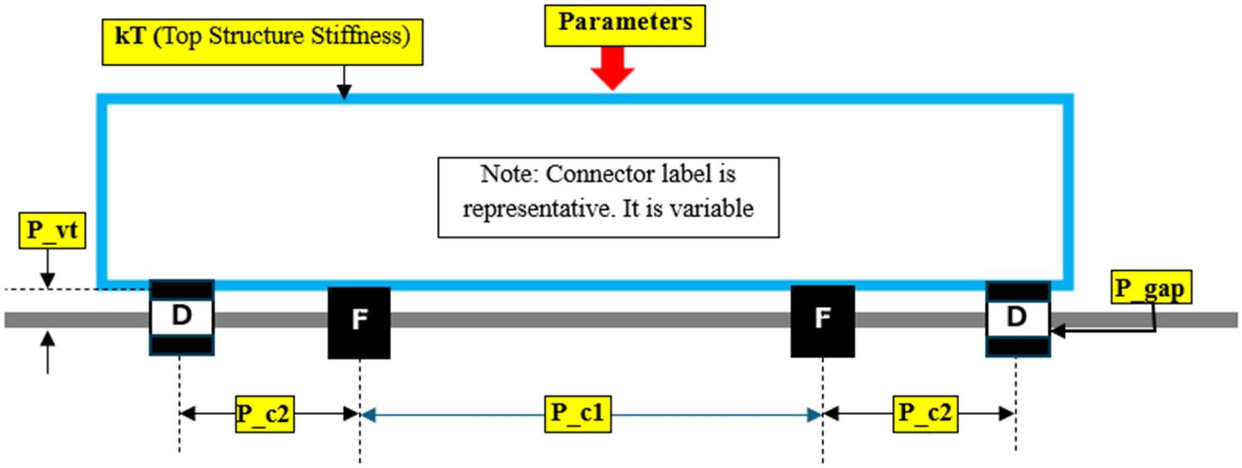


Fig. 22.Top Structure - Parameters

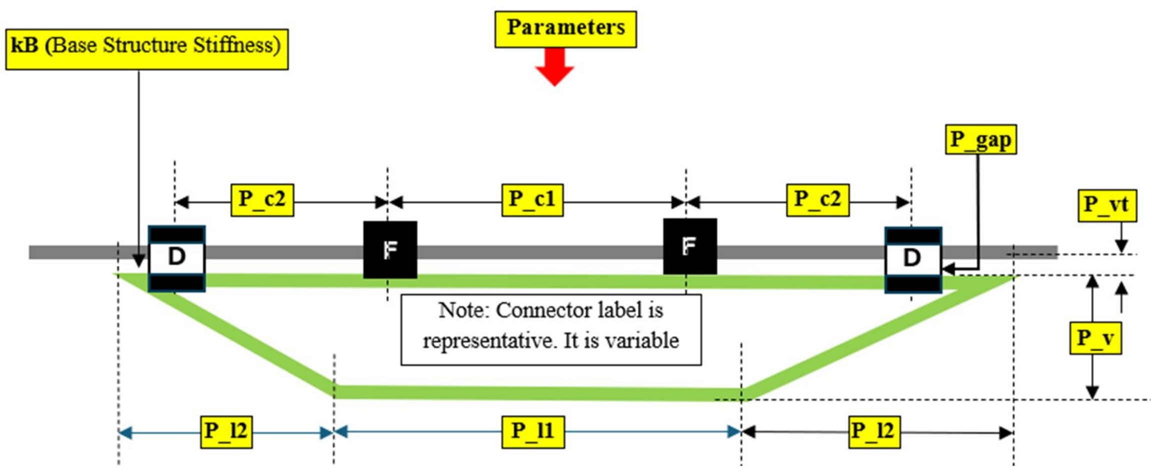


Fig. 23.Base Structure – Parameters

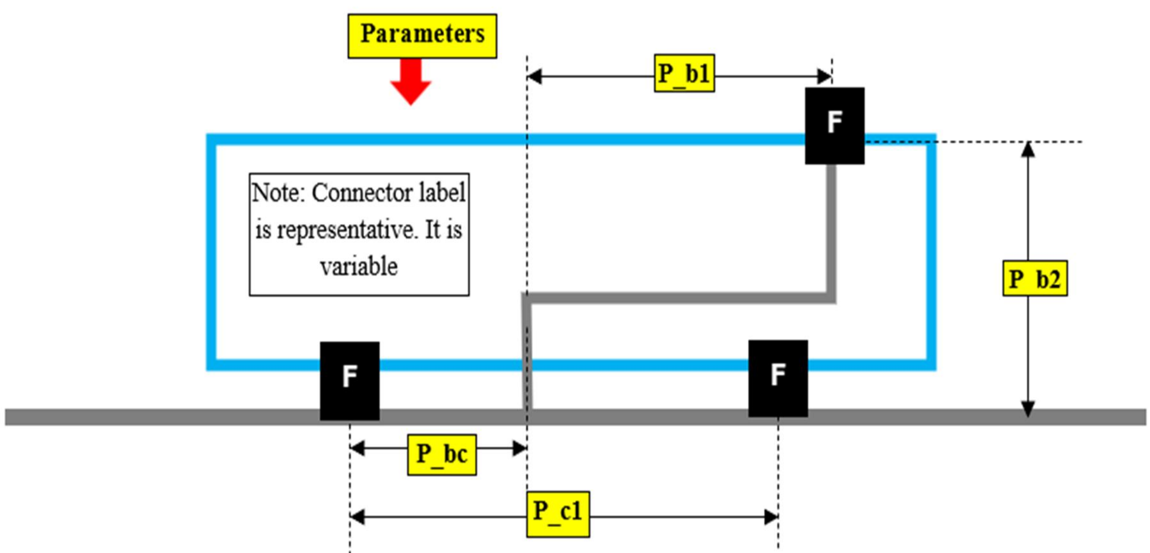


Fig. 24. Z Branch Piping Layout - Parameters

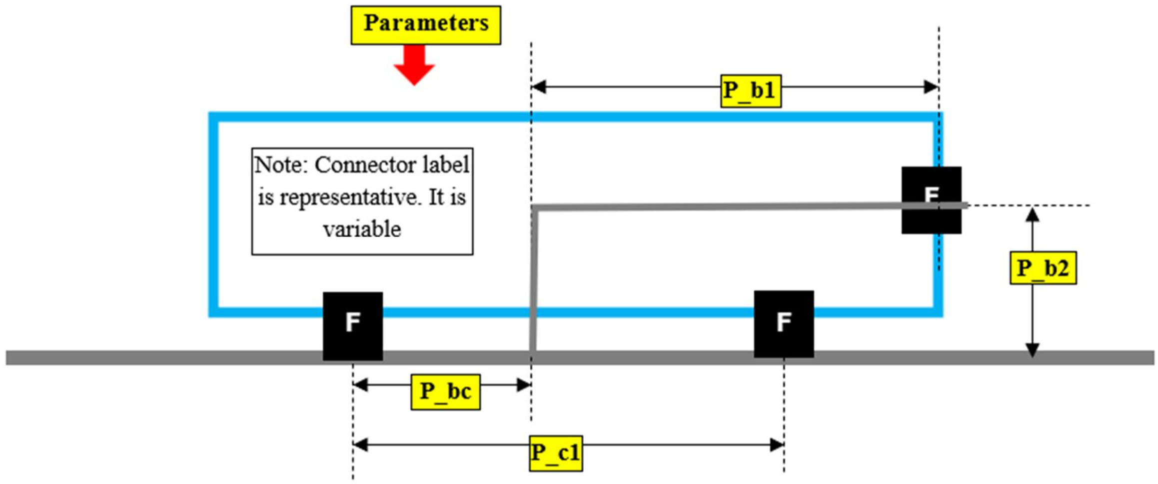


Fig. 25. L Branch Piping Layout - Parameters

TABLE VIII. PARAMETERS SUMMARY

Component / Connector	Engineering Parameters	Design Parameters
EA-ST (See Fig. 22)	**P_c1, P_c2** : Connector Locations **kT**: Top Structure Stiffness between connection points **P_vt**: Distance of Structure base frame from Pipe C/L	Other Geometrical Details
EA-SB (See Fig. 23)	**P_c1, P_c2** : Connector Locations **P_l1, P_l2, P_v** : Base Structure Dimensions **kB**: Base Structure Stiffness between connection points **P_vt**: Distance of Structure top frame from Pipe C/L	
D (Deadband) (See Fig. 22, Fig. 23)	**P_gap** - Gap in the connection before contact	
IW-BZ (See Fig. 24)	**P_c1, P_c2** : Connector Locations w.r.t TEE **P_bc, P_b1, P_b2** : Branch Dimensions	
IW-BL (See Fig. 25)	**P_c1, P_c2** : Connector Locations w.r.t TEE **P_bc, P_b1, P_b2** : Branch Dimensions	

VI. ENGINEERING METHODOLOGY - FEA MODEL

The Abaqus modelling methodology follows [1]: pipeline modelled with B31 beam elements (mesh = 2×OD), rigid rollers of 300 mm radius at 8–9 m spacing along the stinger arc and firing line, frictionless contact, and the five-step loading sequence (pretension, catenary rotation, gravity, lay tension, translation). Refer Fig. 26 for an overview of the model.

All studies in this paper use the 16 in pipeline reference geometry (406 mm OD × 21 mm WT) at R = 85 m and T = 100 MT unless stated. Plain-pipe baseline strain for this configuration: 0.33% (Phase 2 start) to 0.38% (start between SR1–SR2). Three modelling extensions are introduced beyond [1]:

1) Structure frames. Base and Top Structures are modelled as 2D beam frames. The structure underside contacts the rollers directly in Base Structure (V>0) cases.

2) Point mass. Added mass is represented by Abaqus Inertia elements placed at specified pipeline nodes, decoupled from any stiffness contribution — this isolates mass as an independent variable.

3) Branch piping. The branch (10 in OD × 15.9 mm WT) connects to the header via the Tee and to its support via BEAM (fixed) or SLOT (sliding) connectors; valve and connector masses (3.5 MT each) are applied as Inertia elements at their spool positions.

A modelling note common to the structure and branch studies: bulkheads and thick inline components required to physically anchor structures to the pipeline are intentionally NOT modelled. This isolates the connection-layout effect; the thick-component strain contribution characterized in [1] must be superimposed at connection points for a full design assessment. Reported strains are for relative comparison (pattern recognition), not absolute code compliance.

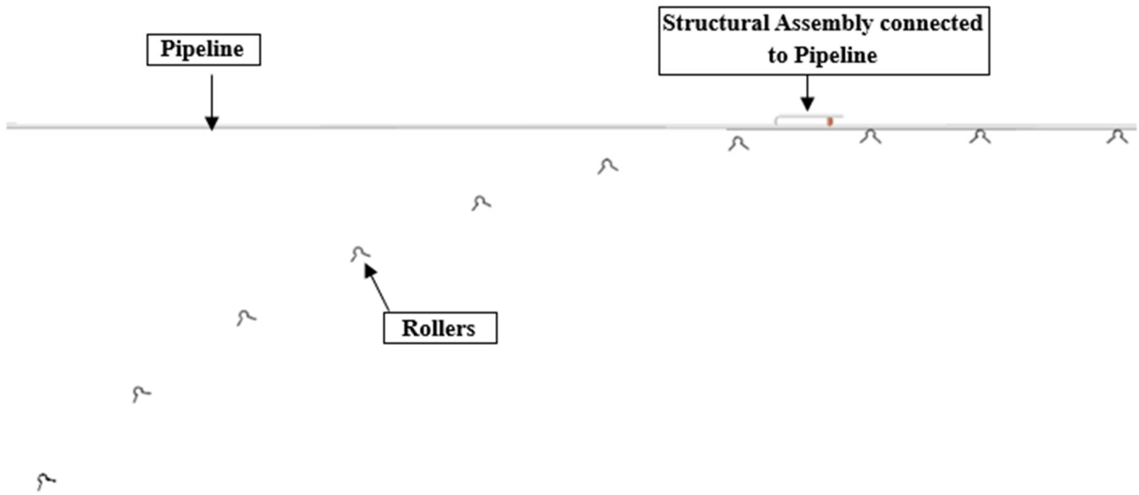


Fig. 26. Analysis Model Overview

VII. BEHAVIOUR STUDY: TOP STRUCTURE (EA-ST)

A. Introduction

This section presents the description and details of the analyses done to make inferences regarding Top Structure behaviour.
Stinger and Pipeline parameters are as per below

TABLE IX.. STINGER AND PIPELINE PROPERTIES

Item	Value	Remarks
Stinger Radius	85m	Much variety in these parameters is not required for this study, as the aim is to identify effects related to Structural arrangement.
Pipeline OD	406.4mm	
Pipeline Wall thickness	21mm	
Pipeline Tension	100 mT	

B. Pipeline Regions Classification for Results Summary

Refer Fig. 27 for how various regions within the ILS Header piping are classified for summarising the results. Following 4 regions are applicable currently

X_c: Region near the connector. 2 x Pipe OD on either side of the connector point
X_i and **X_i2 :** refer to interior regions
X_e : refers to pipeline outside the structures.
Nominal Strains at element integration points are reported here.

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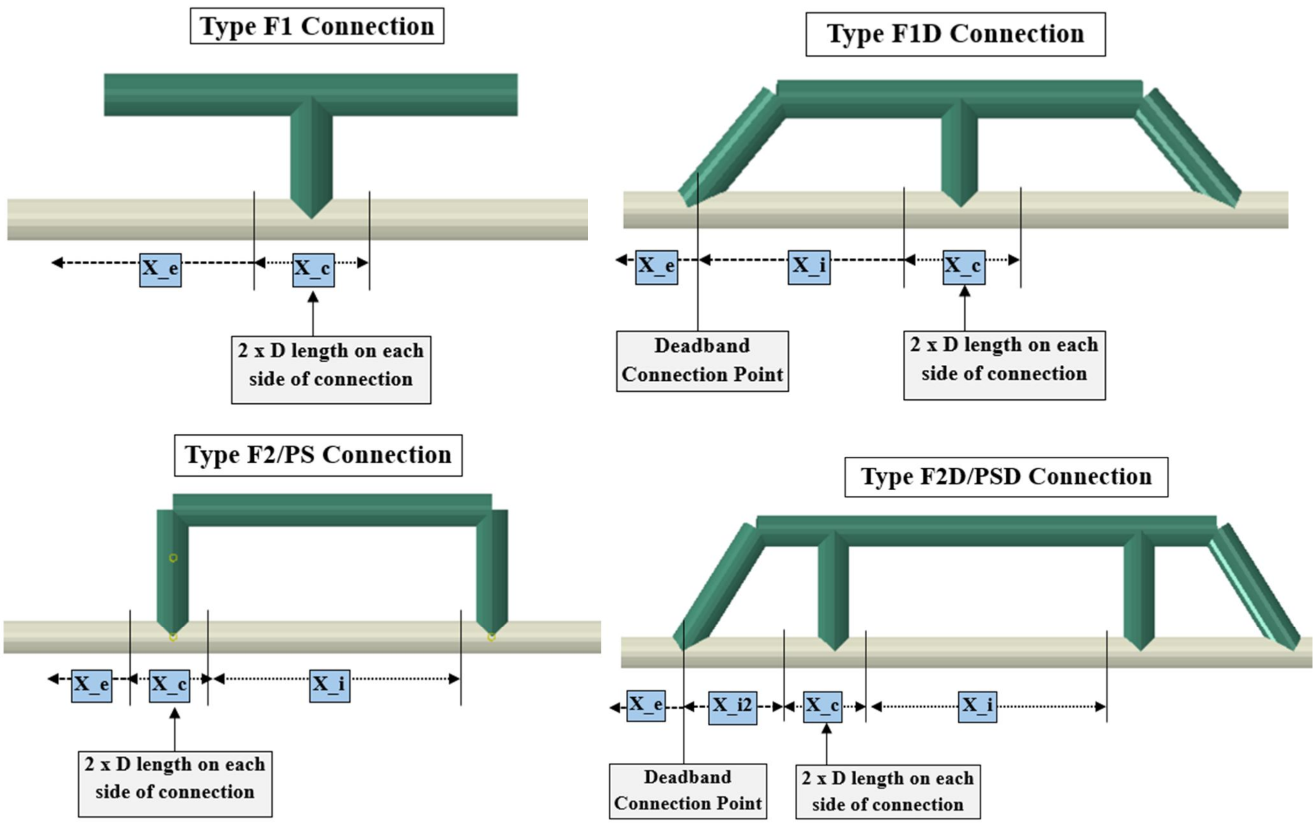

Fig. 27. Pipeline Region Classification for Results Summary

C. Study Details ad Results: EA-ST with Connection Type F1

Results:

Case	**Peak Strain (NE)**	
	X_c	**X_e**
Case 1	0.33%	0.33%

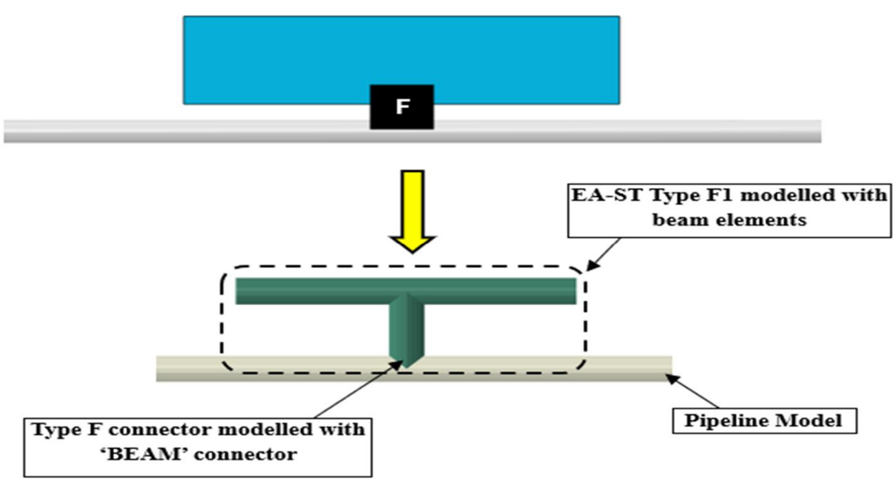

Fig. 28. Type F1 Connection - Analysis Model

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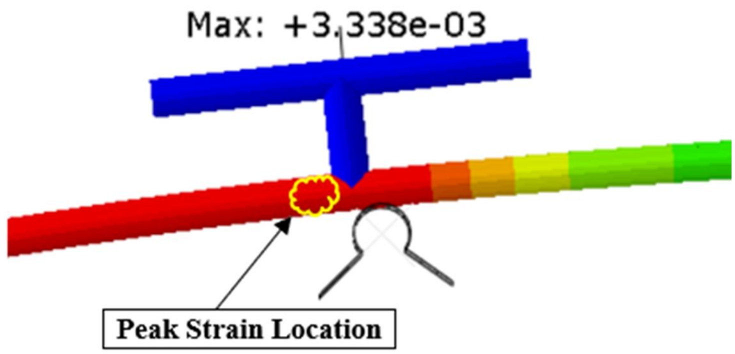

Fig. 29. Type F1 Connection - Strain results

D. Study: EA-ST with Connection Type F1D

Parameters:

Parameter	Value	
	Case 1	Case 2
P_c2	7.5D	
P_gap	50mm	100mm
kT	2.52 x Pipeline Stiffness	

Results:

Case	Peak Strain (NE)		
	X_c	X_i	X_e
Case 1	0.266%	0.388%	0.396%
Case 2	0.336%	0.352%	0.379%

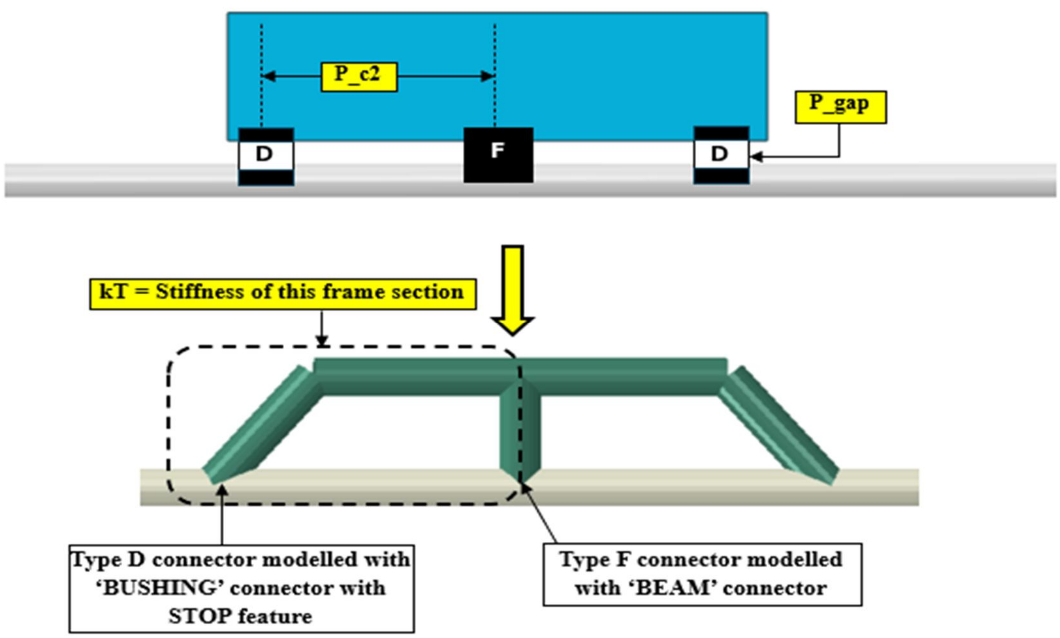

Fig. 30. Type F1D Connection - Analysis Model

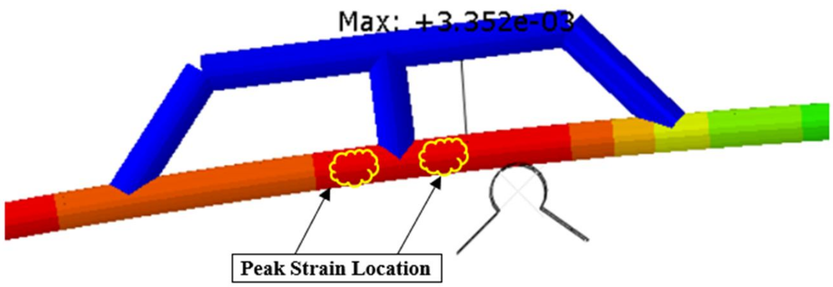

Fig. 31. Type F1D Connection - Strain results

E. Study: EA-ST with Connection Type F2

Parameters:

Parameter	Value	
	Case 1	**Case 2**
P_c1	10D	20D
kT	2.22 x Pipeline Stiffness	2.85 x Pipeline Stiffness

Results:

Case	Peak Strain (NE)		
	X_c	**X_i**	**X_e**
Case 1	0.936%	0.043%	0.732%
Case 2	1.41%	0.075%	1.021%

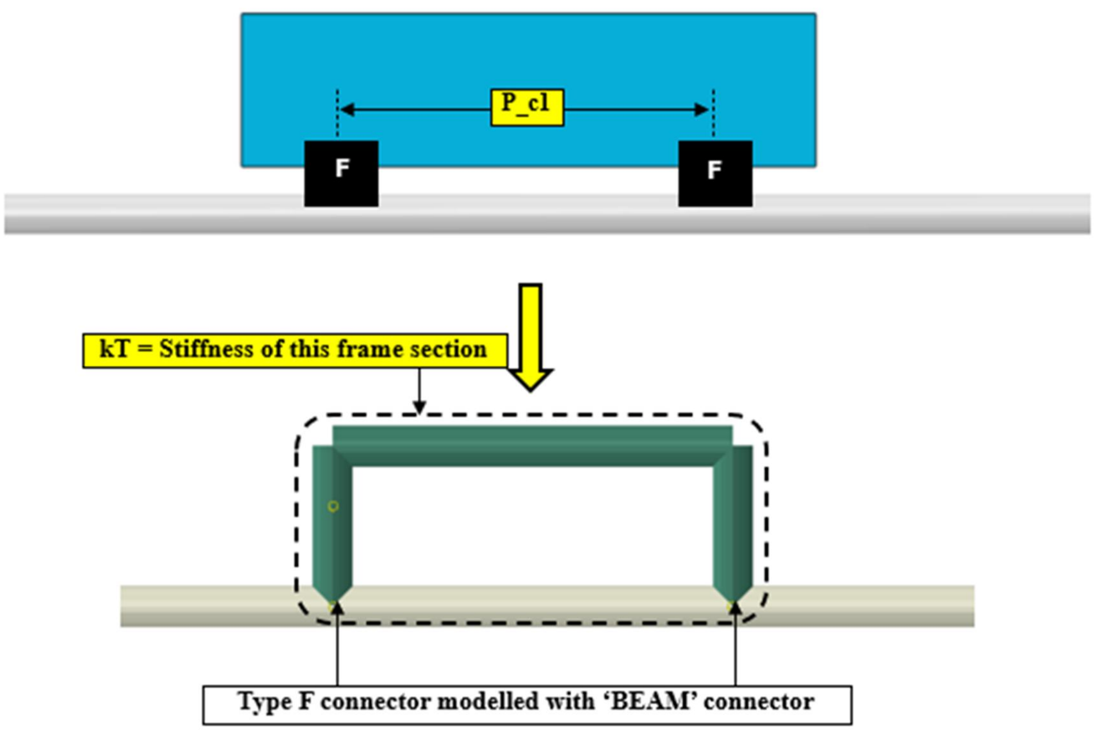

Fig. 32. Type F2 Connection - Analysis Model

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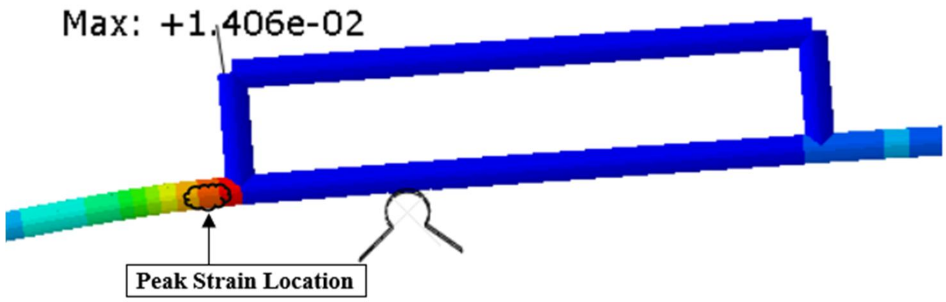

Fig. 33. Type F2 Connection - Strain results (Case 2)

F. Study: EA-ST with Connection Type F2D

Parameters:

Parameter	Value	
	Case 1	Case 2
P_c1	10D	
P_c2	5D	
kT1	2.22 x Pipeline Stiffness	
kT2	2.52 x Pipeline Stiffness	
P_gap	50mm	25mm

Results:

Case	Peak Strain (NE)			
	X_c	X_i1	X_i2	X_e
Case 1	0.325%	0.042%	0.681%	0.685%
Case 2	0.289%	0.037%	0.649%	0.705%

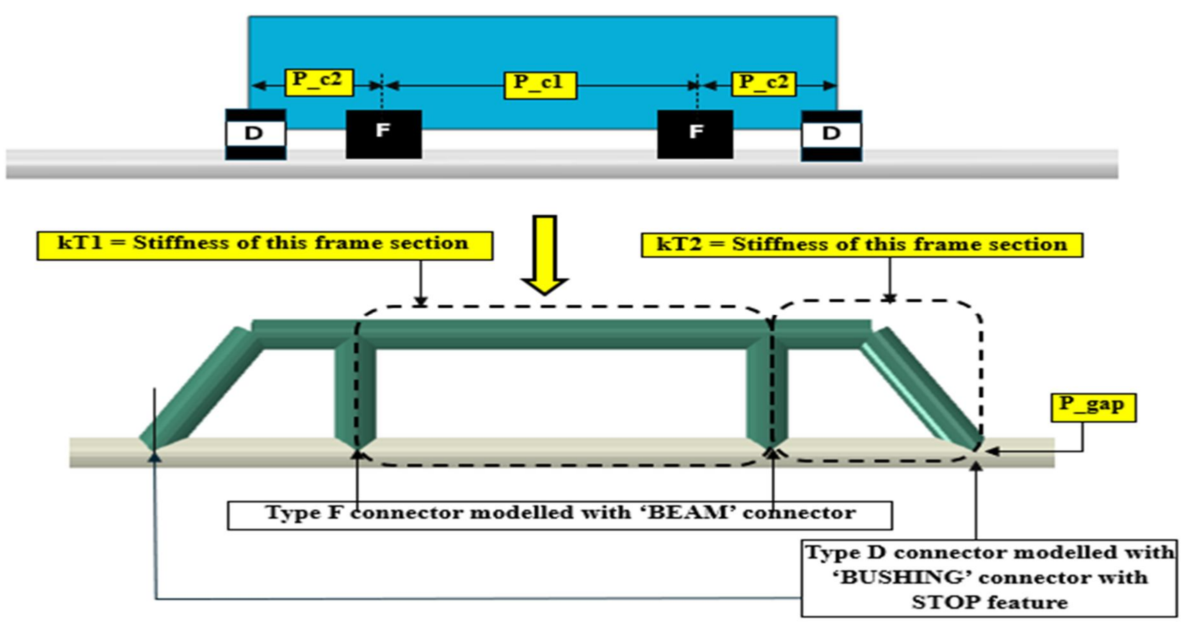

Fig. 34. Type F2D Connection - Analysis Model

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G. Study: EA-ST with Connection Type PS

Parameters:

Parameter	Value
	Case 1
P_c1	10D
kT	2.22 x Pipeline Stiffness

Results:

Case	Peak Strain (NE)		
	X_c	X_i	X_e
Case 1	0.341%	0.335%	0.356%

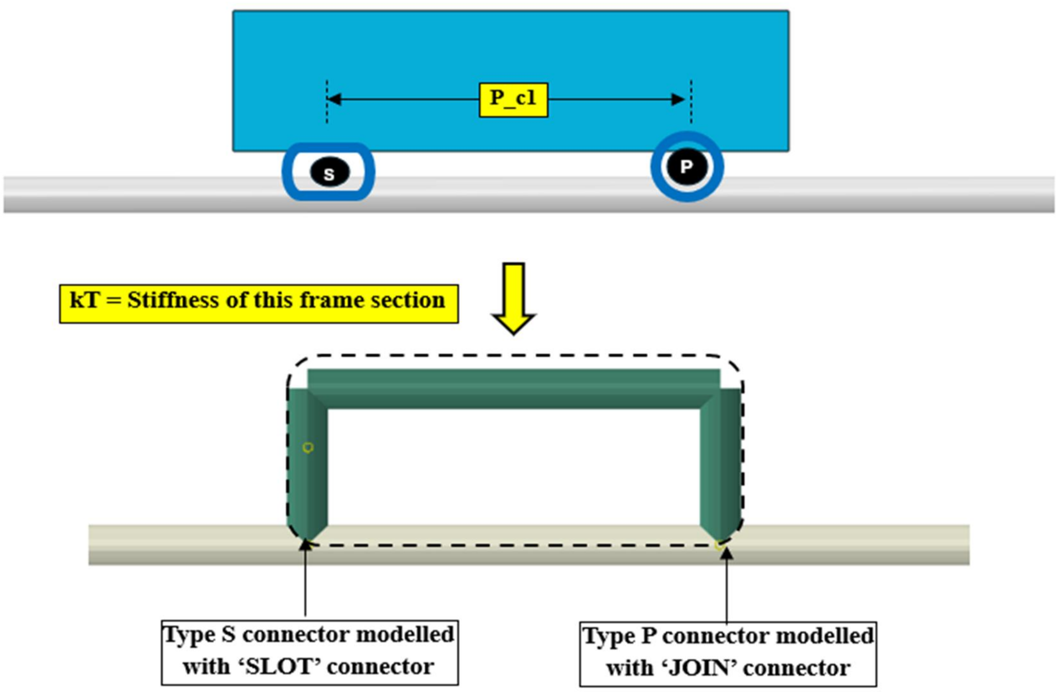


Fig. 35. Type PS Connection - Analysis Model

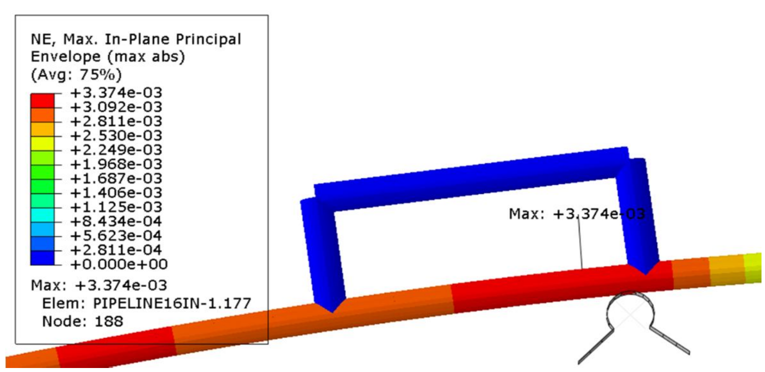


Fig. 36. Type PS Connection - Strain results

H. Study: EA-ST with Connection Type PSD

Parameters:

Parameter	Value
	Case 1
P_c1	10D
P_c2	5D
kT1	2.22 x Pipeline Stiffness
kT2	2.52 x Pipeline Stiffness
P_gap	25mm

Results:

Case	Peak Strain (NE)			
	X_c	X_i1	X_i2	X_e
Case 1	0.308%	0.024%	0.440%	0.460%

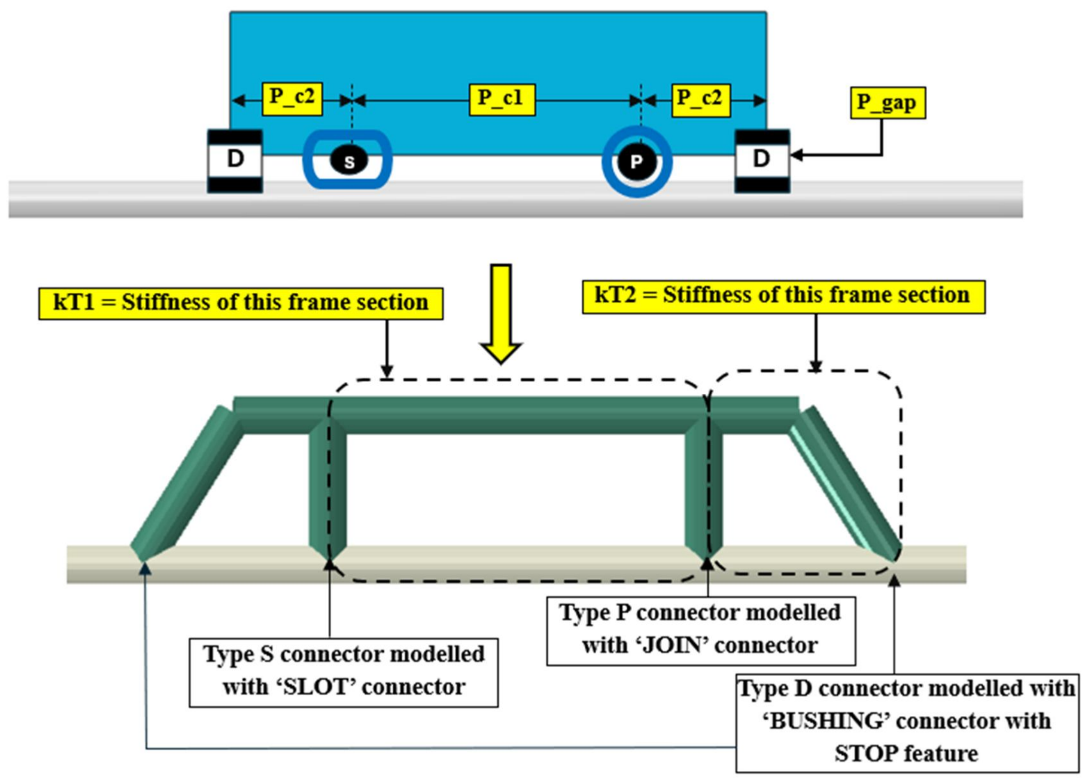


Fig. 37. Type PSD Connection - Analysis Model

I. Summary and Findings – Top Structure (EA-ST)

- F1 (single fixed point) and PS (pin-slot) connections add almost no extra strain to the pipeline. With these two connector types, the strain in the header pipe stays close to the plain-pipe value along the entire length of the structure.
- F2 (fixed at two points) does the opposite: it creates a high strain spike right at the two connection points. Between those points, however, the pipe strain drops well below the plain-pipe value. This low-strain pocket is a useful place to locate strain-sensitive items such as valves.

- Adding a deadband — the "D" in F1D, F2D and PSD — does not remove strain, it moves it. F1D and F2D lower the strain right at the connection, but this strain reappears a short distance away, inside or outside the structure. A deadband should therefore be thought of as a way to relocate strain to a more convenient spot, not as a way to reduce it overall.
- Getting this relocation right depends entirely on controlling the gap size in the D connector. A gap that is too large or too small changes where the strain shows up.
- Overall design guidance: choose F1 or PS when the structure should behave close to a plain pipe. Choose F2, F2D or PSD when a stiff, low-strain deck is needed inside the structure, and accept that some strain will build up where it connects.

J. Limitations and Future Work – Top Structure (EA-ST)

- The connectors in this study sit directly on the pipe centreline. In a real design they are welded slightly off the pipe, through a boss on a bulkhead (IW-A). This offset was left out here to isolate the connector effect, but it will change the local strain a little and could be studied in a future model.
- Only a small set of stiffness, spacing and gap values was tested. A wider parameter sweep is needed before these trends can be used for detailed sizing.

VIII. BEHAVIOUR STUDY: BASE STRUCTURE (EA-SB)

A. Introduction

This section presents the description and details of the analyses done to make inferences regarding Base Structure behaviour. Stinger and Pipeline parameters are as per below

TABLE X. STINGER AND PIPELINE PROPERTIES

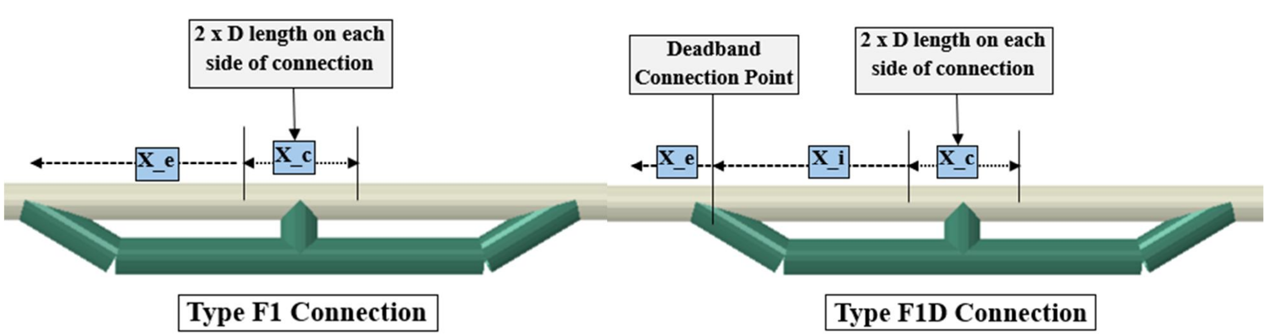
Item	Value	Remarks
Stinger Radius	85m	Much variety in these parameters is not required for this study, as the aim is to identify effects related to Structural arrangement.
Pipeline OD	406.4mm	
Pipeline Wall thickness	21mm	
Pipeline Tension	100 mT	

Note that P_vt is considered as 0 for all cases here.

B. Pipeline Regions Classification for Results Summary

Refer Fig. 38 for how various regions within the ILS Header piping are classified for summarising the results. Following 4 regions are applicable currently

X_c: Region near the connector. 2 x Pipe OD on either side of the connector point
X_i and **X_i2 :** refer to interior regions
X_e : refers to pipeline outside the structures.
<u>Nominal Strains at element integration points are reported here</u>



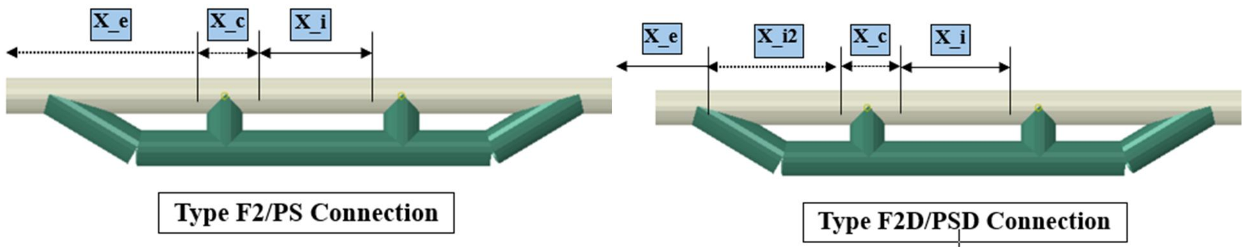


Fig. 38. Pipeline Region Classification for Results Summary

C. Study Details ad Results: EA-SB with Connection Type F1

Parameters:

Parameter	Value
	Case 1
P_l1	5D
P_l2	2.5D
P_v	2D
kB	3.2 x Pipeline Stiffness

Results:

Case	Peak Strain (NE)	
	X_c	X_e
Case 1	2.30%	1.41%

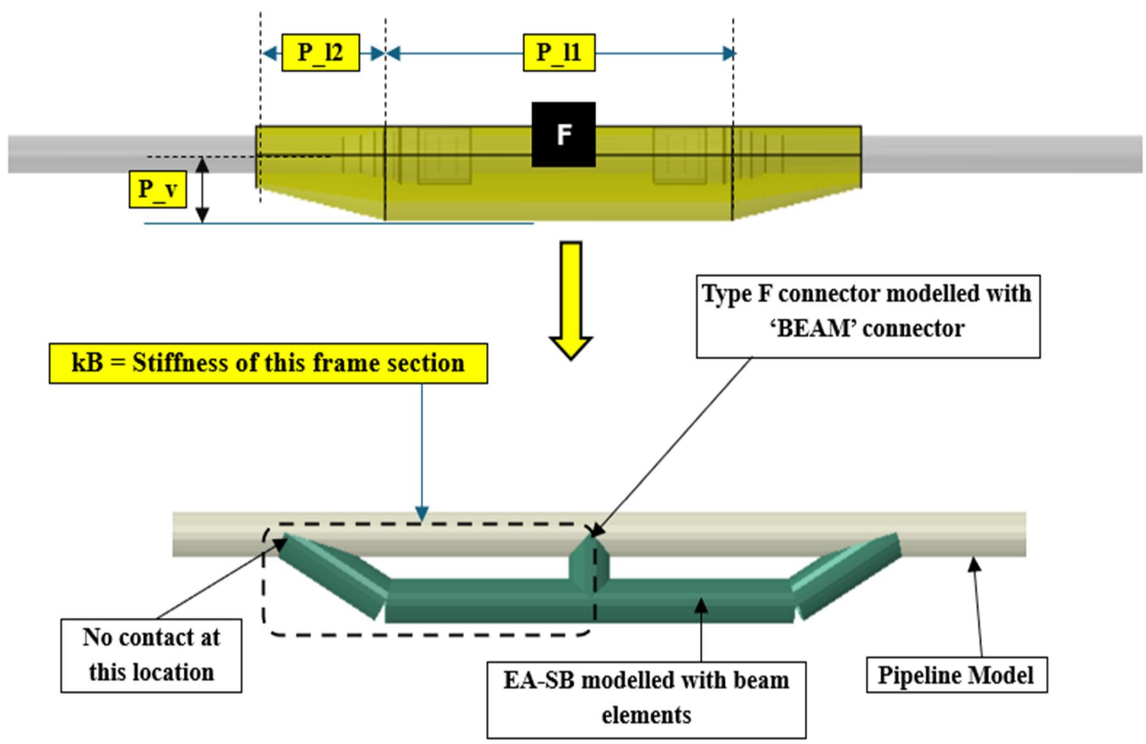


Fig. 39. Type F1 Connection - Analysis Model

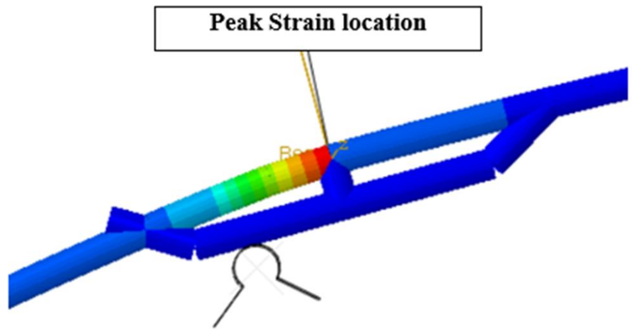


Fig. 40. Type F1 Connection - Strain results

D. Study: EA-SB with Connection Type F1D

Parameters:

Parameter	Value	
	Case 1	Case 2
P_l1	5D	10D
P_l2	2.5D	
P_c2	5D	7.5D
P_v	2D	
P_gap	100mm	
kB	3.2 x Pipeline Stiffness	2.81 x Pipeline stiffness

Results:

Case	Peak Strain (NE)		
	X_c	X_i	X_e
Case 1	1.34%	1.01%	0.536%
Case 2	0.637%	0.826%	0.826%

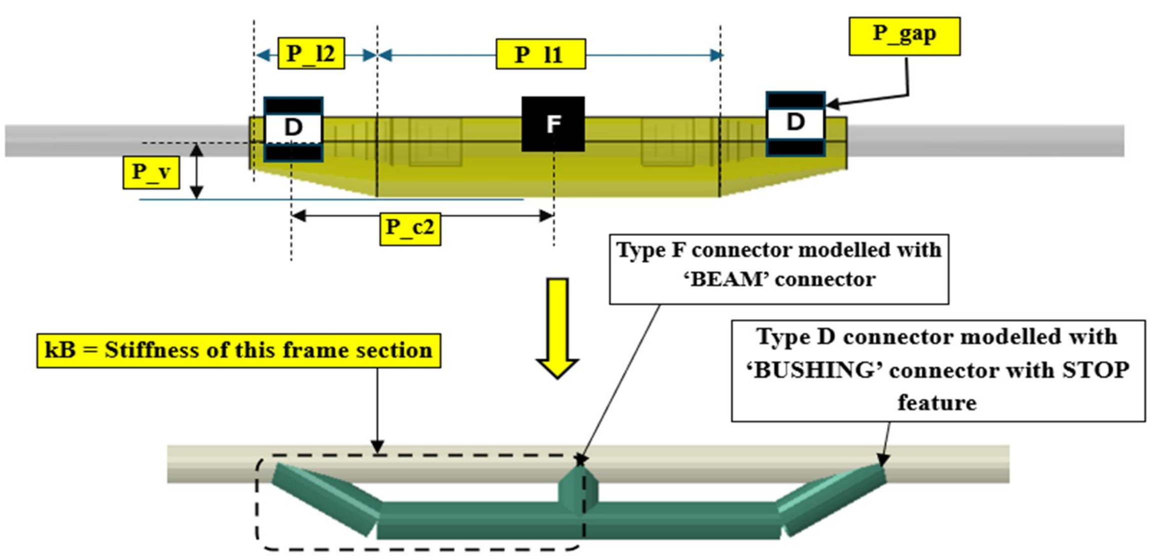


Fig. 41. Type F1D Connection - Analysis Model

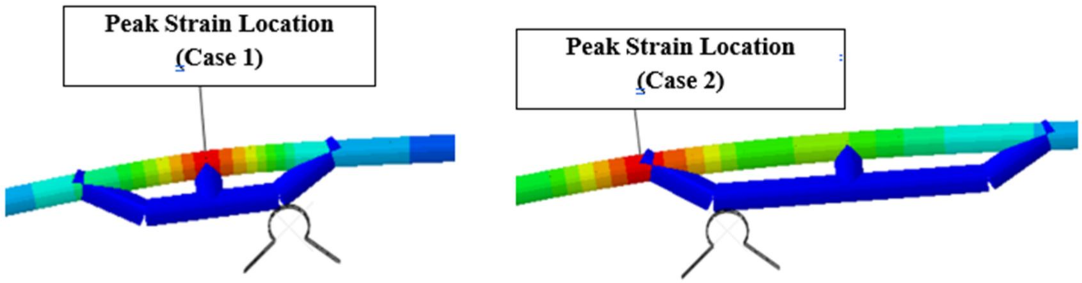


Fig. 42. Type F1D Connection - Strain results

E. Study: EA-SB with Connection Type F2

Parameters:

Parameter	Value		
	Case 1	Case 2	Case 3
P_l1	10D	10D	15D
P_l2	2.5D		
P_c1	5D	10D	10D
P_v	2D		
kB	2.5 x Pipeline Stiffness	3.1 x Pipeline Stiffness	3.1 x Pipeline Stiffness

Results:

Case	Peak Strain (NE)		
	X_c	X_i	X_e
Case 1	2.24%	0.086%	1.45%
Case 2	2.40%	0.086%	1.52%
Case 3	2.53%	0.085%	1.60%

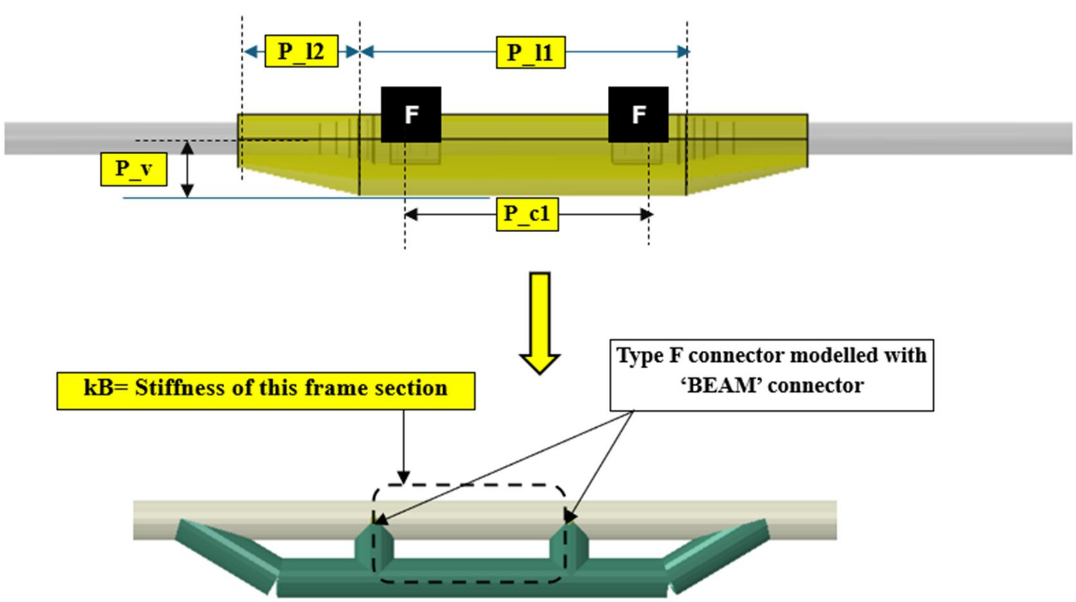


Fig. 43. Type F2 Connection - Analysis Model

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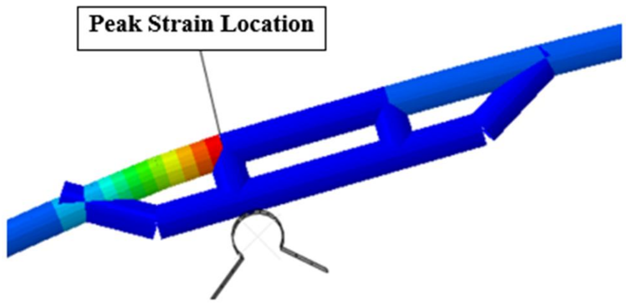

Fig. 44. Type F2 Connection - Strain Results

F. Study: EA-SB with Connection Type F2D

Parameters:

Parameter	Value	
	Case 1	Case 2
P_l1	10D	
P_l2	2.5D	
P_c1	5D	
P_c2	5D	
P_v	2D	
kB1	2.5 x Pipeline Stiffness	
kB2	3.2 x Pipeline Stiffness	
P_gap	100mm	50mm

Results:

Case	**Peak Strain (NE)**			
	X_c	**X_i1**	**X_i2**	**X_e**
Case 1	1.410%	0.089%	0.980%	0.760%
Case 2	0.62%	0.09%	1.15%	1.25%

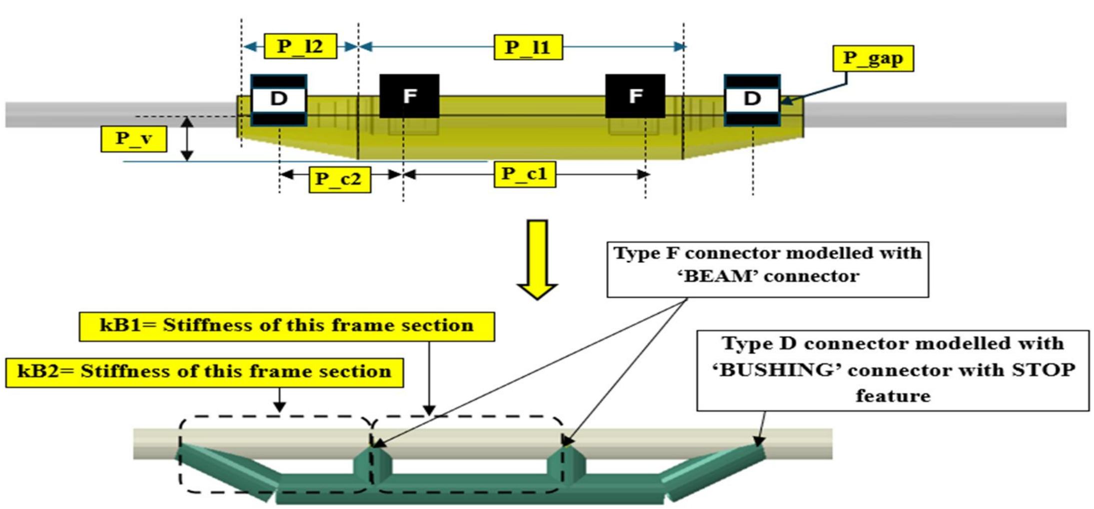

Fig. 45. Type F2D Connection - Analysis Model

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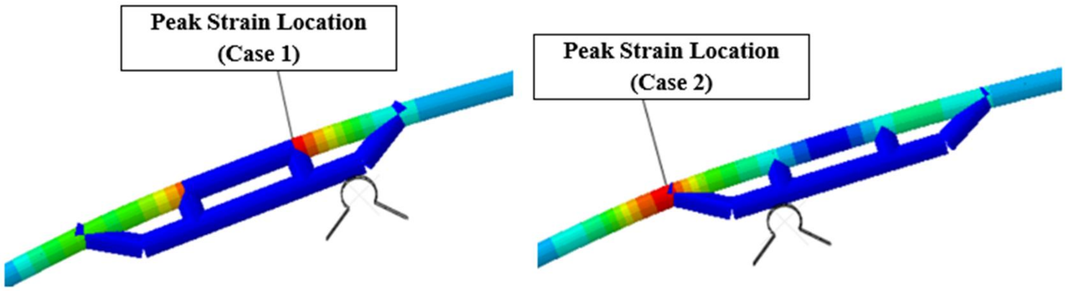

Fig. 46. Type F2D Connection - Strain Results

G. Study: EA-SB with Connection Type PS

Parameters:

Parameter	Value
	Case 1
P_c1	5D
P_v	2D
P_l1	10D
P_l2	2.5D
kB1	2.5 x Pipeline Stiffness
kB2	3.2 x Pipeline Stiffness

Results:

Case	Peak Strain (NE)			
	X_c	X_i1	X_i2	X_e
Case 1	1.316%	0.076%	1.110%	0.035%

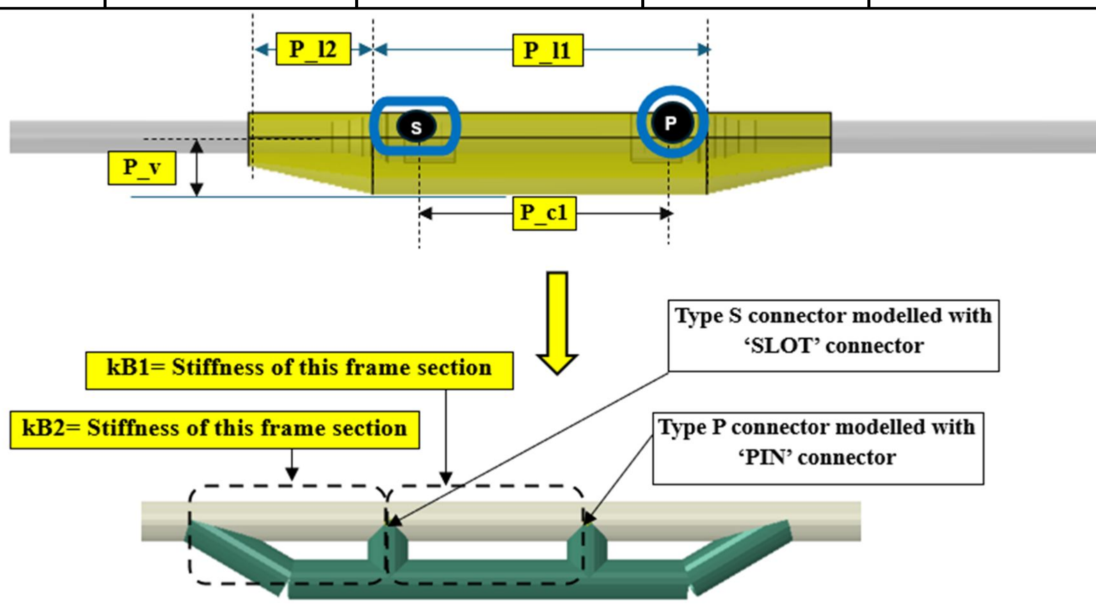

Fig. 47. Type PS Connection - Analysis Model

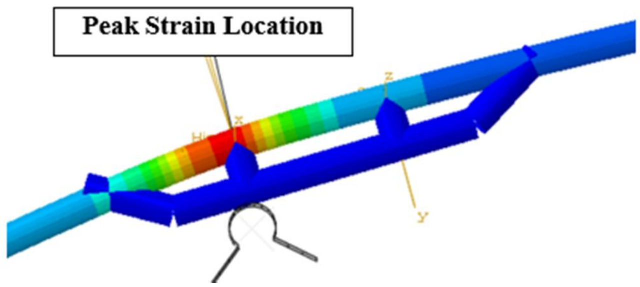

Fig. 48. Type PS Connection - Strain results

H. Study: EA-SB with Connection Type PSD

Parameters:

Parameter	Value
	Case 1
P_c1	5D
P_c2	5D
P_l1	10D
P_l2	2.5D
kB1	2.22 x Pipeline Stiffness
kB2	2.52 x Pipeline Stiffness
P_gap	25mm

Results:

Case	Peak Strain (NE)			
	X_c	X_i1	X_i2	X_e
Case 1	0.670%	0.055%	0.830%	0.840%

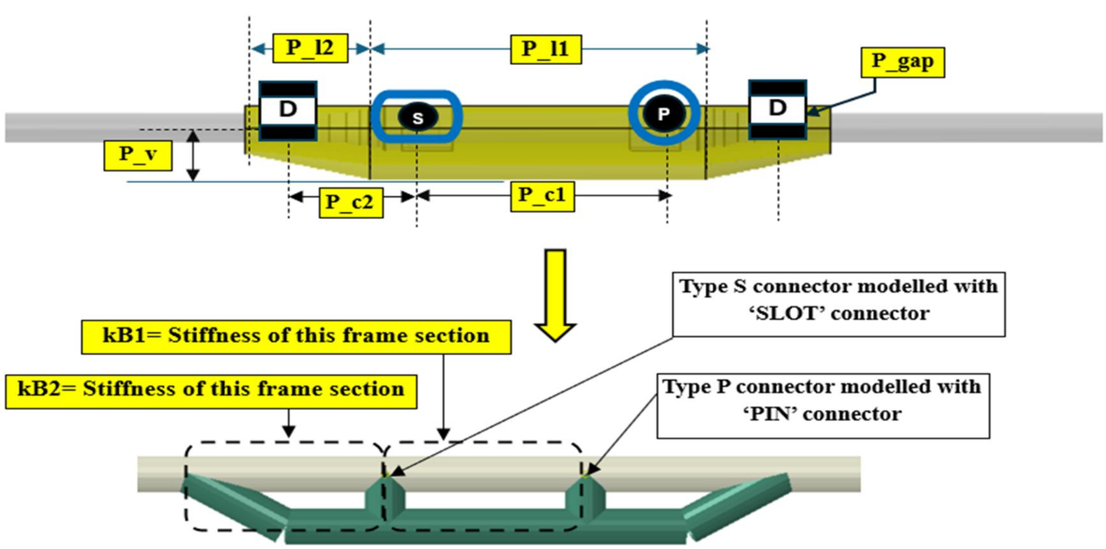

Fig. 49. Type PSD Connection - Analysis Model

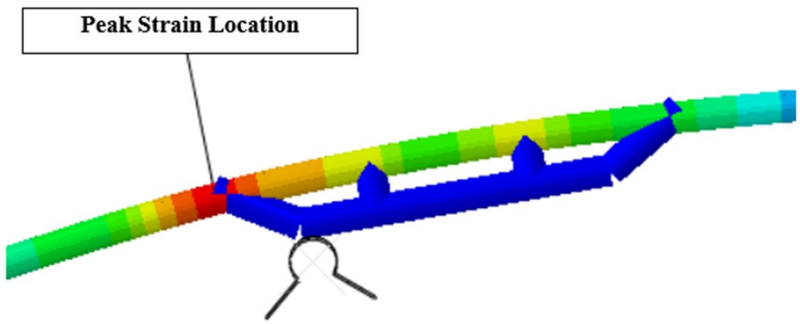

Fig. 50. Type PSD Connection - Strain results

I. Summary and Findings – Base Structure (EA-SB)

- As with the Top Structure, adding a deadband (F1D, F2D) lowers the peak strain compared with the plain F1 or F2 arrangement.
- Unlike the Top Structure, the PS (pin-slot) connector is not very good at lowering strain on a Base Structure — its behaviour is closer to F2 than to F1. If low strain is the goal for a Base Structure, F2D is the better choice.
- F2, F2D, PS and PSD all create a lower-strain zone inside the structure that can hold strain-sensitive equipment, in the same way as for the Top Structure. This again depends on good control of the gap in the D connector.
- F1D lowers strain inside the structure but raises it just outside — the same trade-off as for the Top Structure, and further confirmation that a deadband redistributes strain rather than removing it.
- F2D spreads out the high strain that would otherwise build up right at the connection points, giving a more even strain profile along the structure.

J. Limitations and Future Work – Base Structure (EA-SB)

- Connections were modelled at the pipe centreline for the same reason as the Top Structure study. In practice the Base Structure usually connects through a boss welded to an IW-A bulkhead, which sits at an offset from the pipe; this should be added in future models.
- More combinations of stiffness, spacing and gap should be studied to build a complete design chart.

IX. PARAMETRIC EVALUATION: ADDED MASS EFFECTS

A. Study and Results

Added mass (M = 40 MT total, representative of inline components or structural assemblies) is applied as point Inertia elements in three distribution patterns — concentrated at one node, split across two nodes at 5 m spacing, and split across three nodes at 2.5 m spacing — each evaluated at two stinger positions: centred on roller SR2, and mid-span between SR1 and SR2. Plain-pipe baseline: 0.38%.

TABLE XI. ADDED MASS RESULTS — POSITION AND DISTRIBUTION EFFECTS (M = 40 MT)

Mass Pattern	Peak Strain	Remarks
Case 1: 1 point (concentrated)	0.44	About +16% more than plan pipe baseline
Case 2: 2 points, 5 m spacing	0.44	(+16%) No difference from 2 point case
Case 3: 3 points, 2.5 m spacing	0.45	(+18%). Negligible difference from single point and 2 point distribution
Plain pipeline baseline	0.38	R=85m, T=100MT

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X. BEHAVIOUR EVALUATION: BRANCH PIPING (IW-B) SUPPORT LAYOUTS

A. Introduction

This section presents the description and details of the analyses done to make inferences regarding Branch Pipe behaviour.
Stinger and Pipeline parameters are as per below

TABLE XII. STINGER AND PIPELINE PROPERTIES

Item	Value	Remarks
Stinger Radius	85m	Much variety in these parameters is not required for this study, as the aim is to identify effects related to Structural arrangement.
Header Pipeline OD	406.4mm	
Header Pipeline Wall thickness	21mm	
Branch Pipeline OD	273.1mm	
Branch Pipeline Wall thickness	15.9mm	
Pipeline Tension	100 mT	

B. Pipeline Regions Classification for Results Summary

Refer Fig. 51 for how various regions within the ILS Piping are classified for summarising the results. Following 2 regions are applicable currently

- **Branch Piping**
- **Header Pipeline**

Nominal Strains at element integration points are reported here

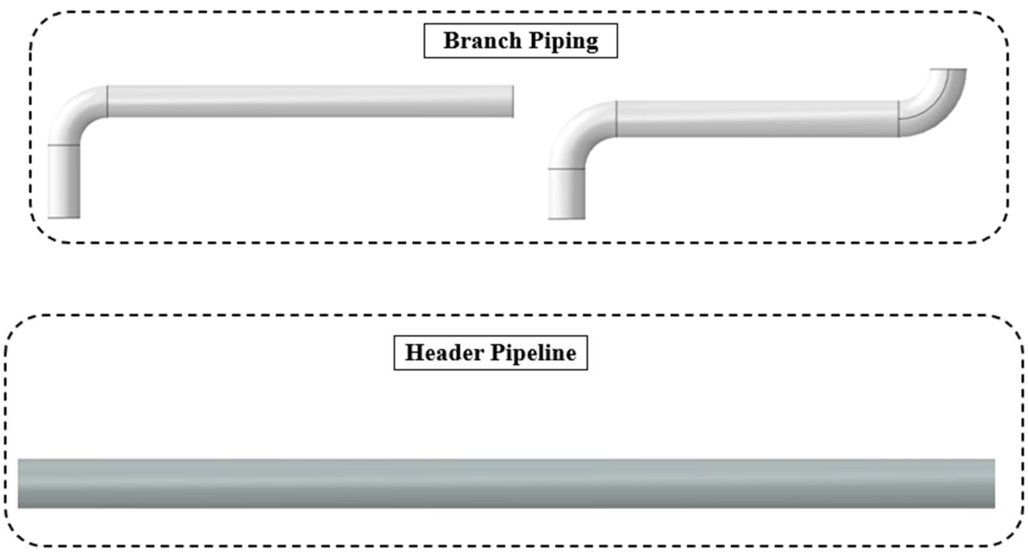

Fig. 51. Pipeline Region Classification for Results Summary

C. Study: L-Branch Fixed connection to Top Structure F1: L-FT-F1

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	2D

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Results:

Case	Peak Strain (NE)	
	Header Pipeline	**Branch Piping**
Case 1	0.740%	0.50% (Tee outlet)

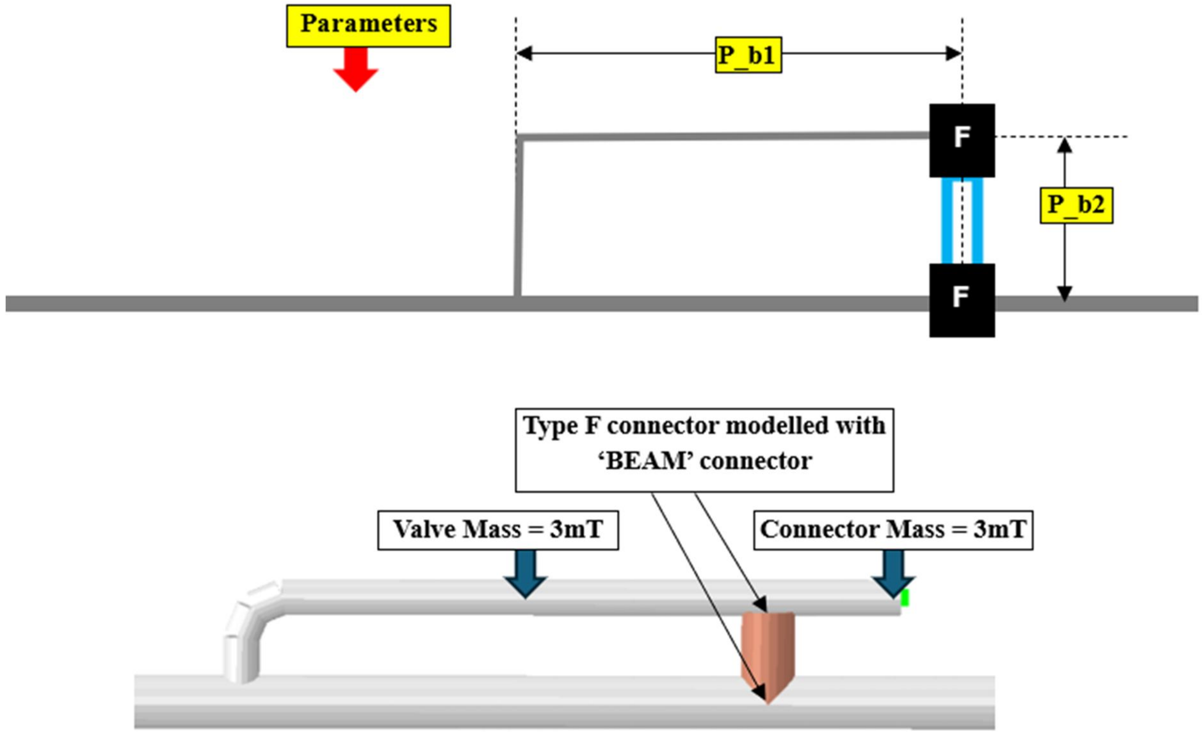

Fig. 52. Type L-FT-F1 Layout - Analysis Model

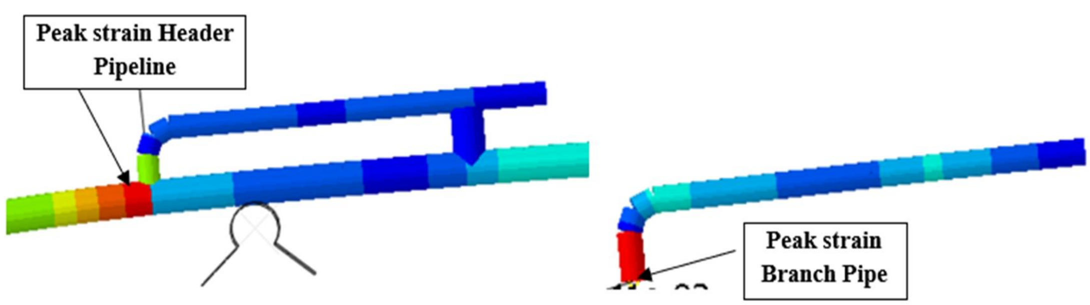

Fig. 53. Strain results

D. Study: L-Branch Sliding connection to Top Structure F1: L-ST-F1

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	2D

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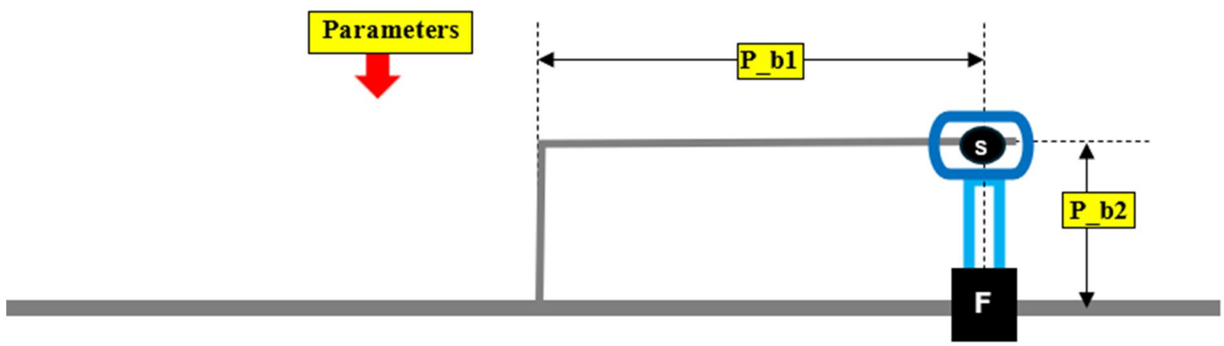
Results:

Case	Peak Strain (NE)	
	Header Pipeline	Branch Piping
Case 1	0.380%	0.12% (Tee outlet)



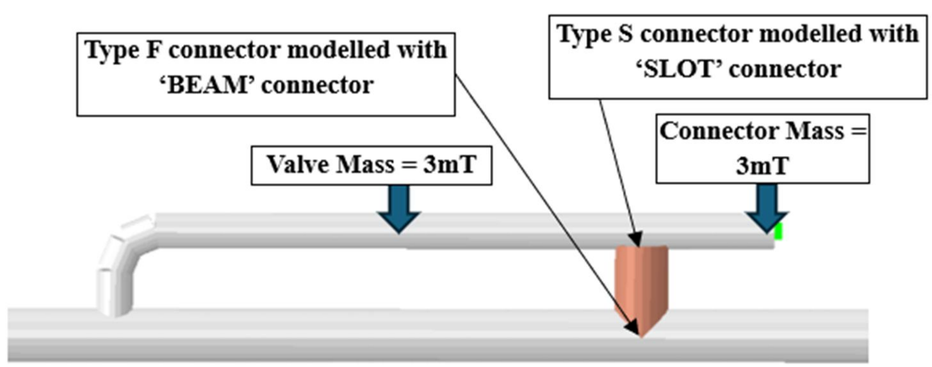


Fig. 54. Type L-ST-F1 Layout - Analysis Model

E. L-Branch Fixed connection to Top Structure F2: L-FT-F2

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	2D
P_bc	2.5D
P_c1	12.5D

Results:

Case	Peak Strain (NE)	
	Header Pipeline	Branch Piping
Case 1	1.19% (At Frame connection)	0.06% (Tee outlet)

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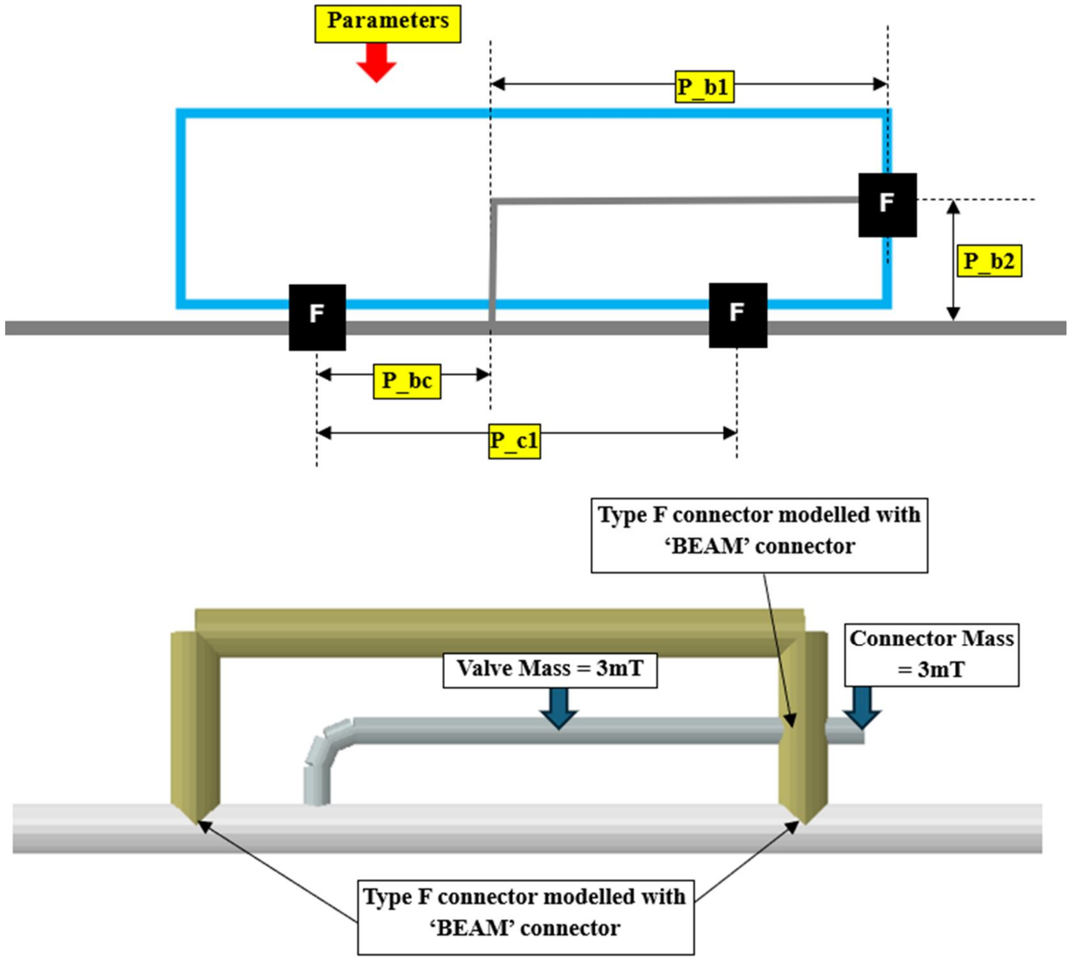

Fig. 55. Type L-FT-F2 Layout - Analysis Model

F. L-Branch Sliding connection to Top Structure F2: L-ST-F2

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	2D
P_bc	2.5D
P_c1	12.5D

Results:

Case	Peak Strain (NE)	
	Header Pipeline	Branch Piping
Case 1	1.19% (At Frame connection)	0.03% (Tee outlet)

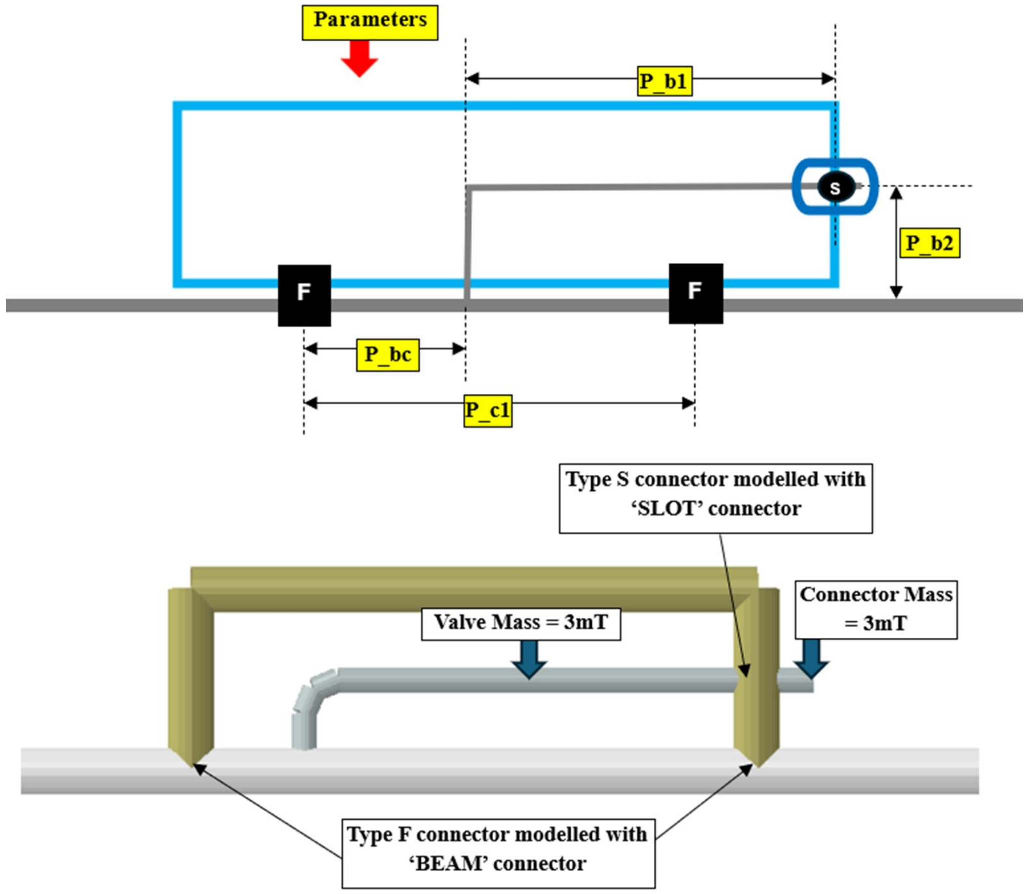

Fig. 56. Type L-ST-F2 Layout - Analysis Model

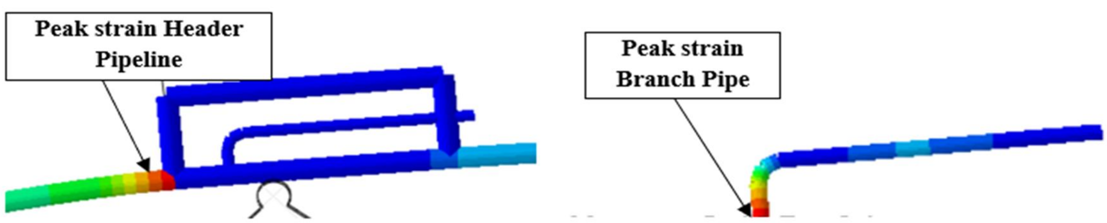

Fig. 32. Strain Results

G. L-Branch Fixed connection to Top Structure PS: L-FT-PS

Parameters:

Parameter	**Value**
	Case 1
P_b1	10D
P_b2	2D
P_bc	2.5D
P_c1	12.5D

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Results:

Case	Peak Strain (NE)	
	Header Pipeline	**Branch Piping**
Case 1	0.39% (General)	0.22% (Tee outlet)

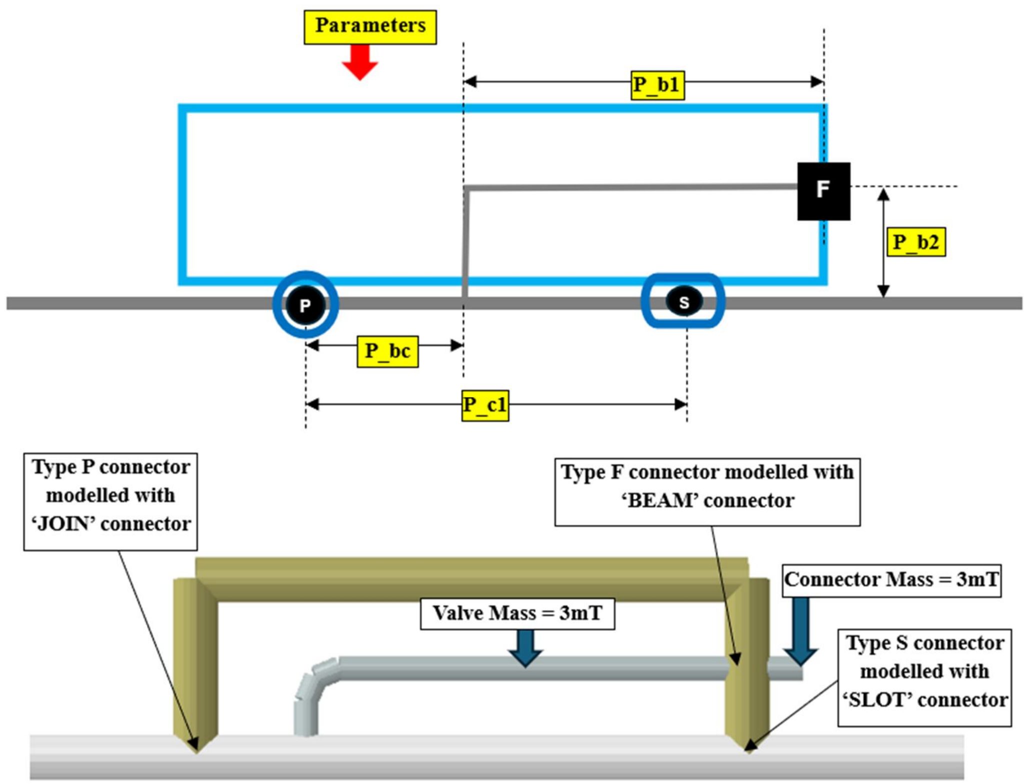

Fig. 57. Type L-FT-PS Layout - Analysis Model

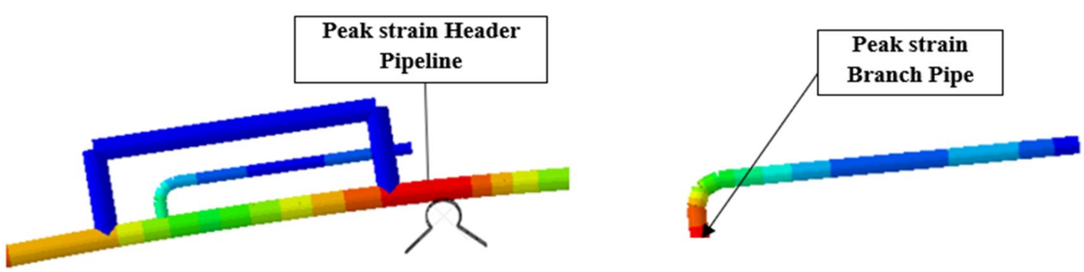

Fig. 58. Strain Results

H. L-Branch Sliding connection to Top Structure PS: L-ST-PS

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	2D
P_bc	2.5D
P_c1	12.5D

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Results:

Case	Peak Strain (NE)	
	Header Pipeline	**Branch Piping**
Case 1	0.37% (General)	0.13% (Tee outlet)

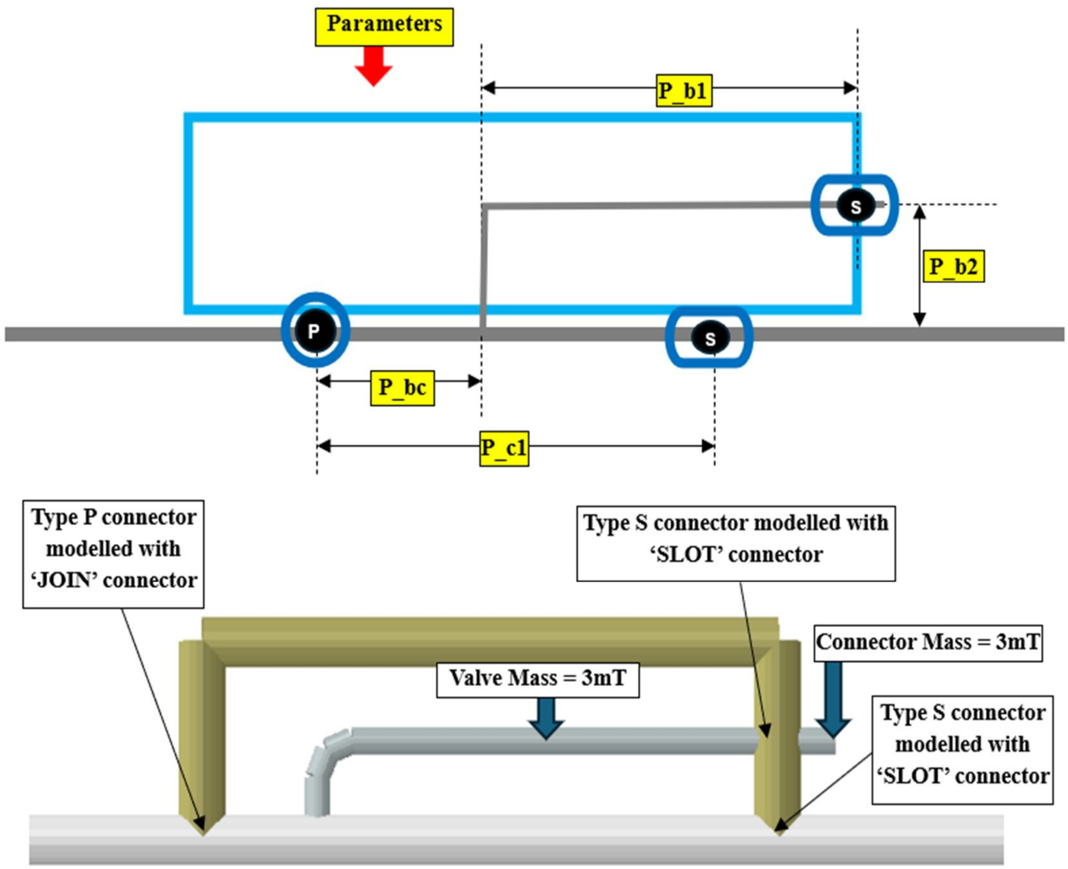

Fig. 59. Type L-ST-PS Layout - Analysis Model

I. Z-Branch Sliding connection to Top Structure F1: Z-FT-F1

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	3.5D

Results:

Case	Peak Strain (NE)	
	Header Pipeline	**Branch Piping**
Case 1	0.760%	0.36% (Tee outlet)

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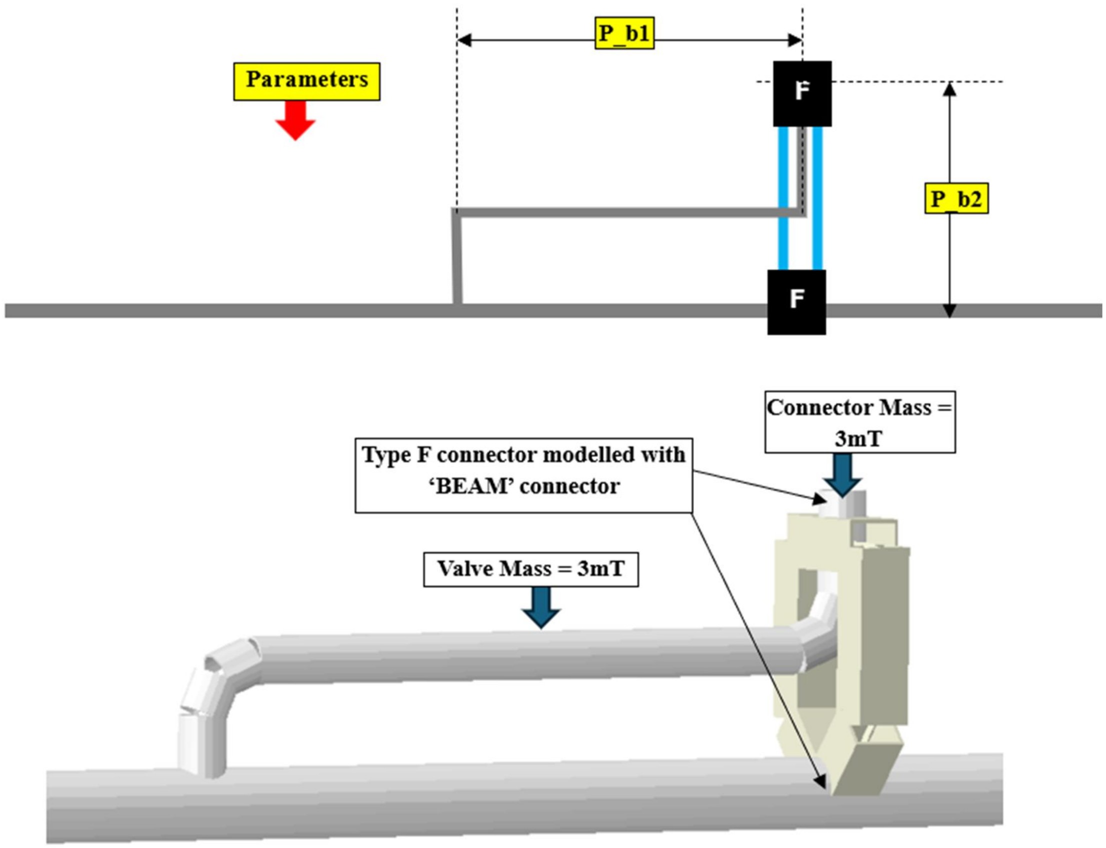

Fig. 60. Type Z-FT-F1 Layout - Analysis Model

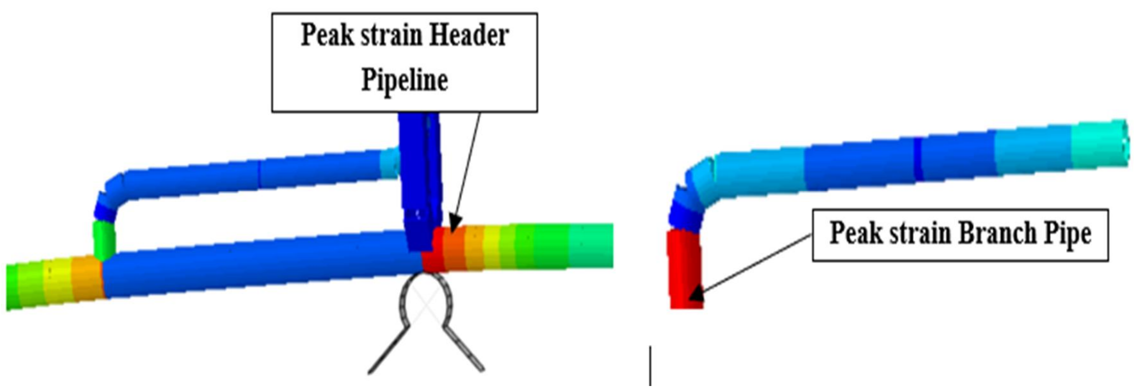

Fig. 61. Strain results

J. Z-Branch Sliding connection to Top Structure F2: Z-FT-F2

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	3.5D
P_bc	1.25D
P_c1	12.5D

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Results:

Case	Peak Strain (NE)	
	Header Pipeline	Branch Piping
Case 1	1.21% (At Frame connection)	0.05% (Tee outlet)

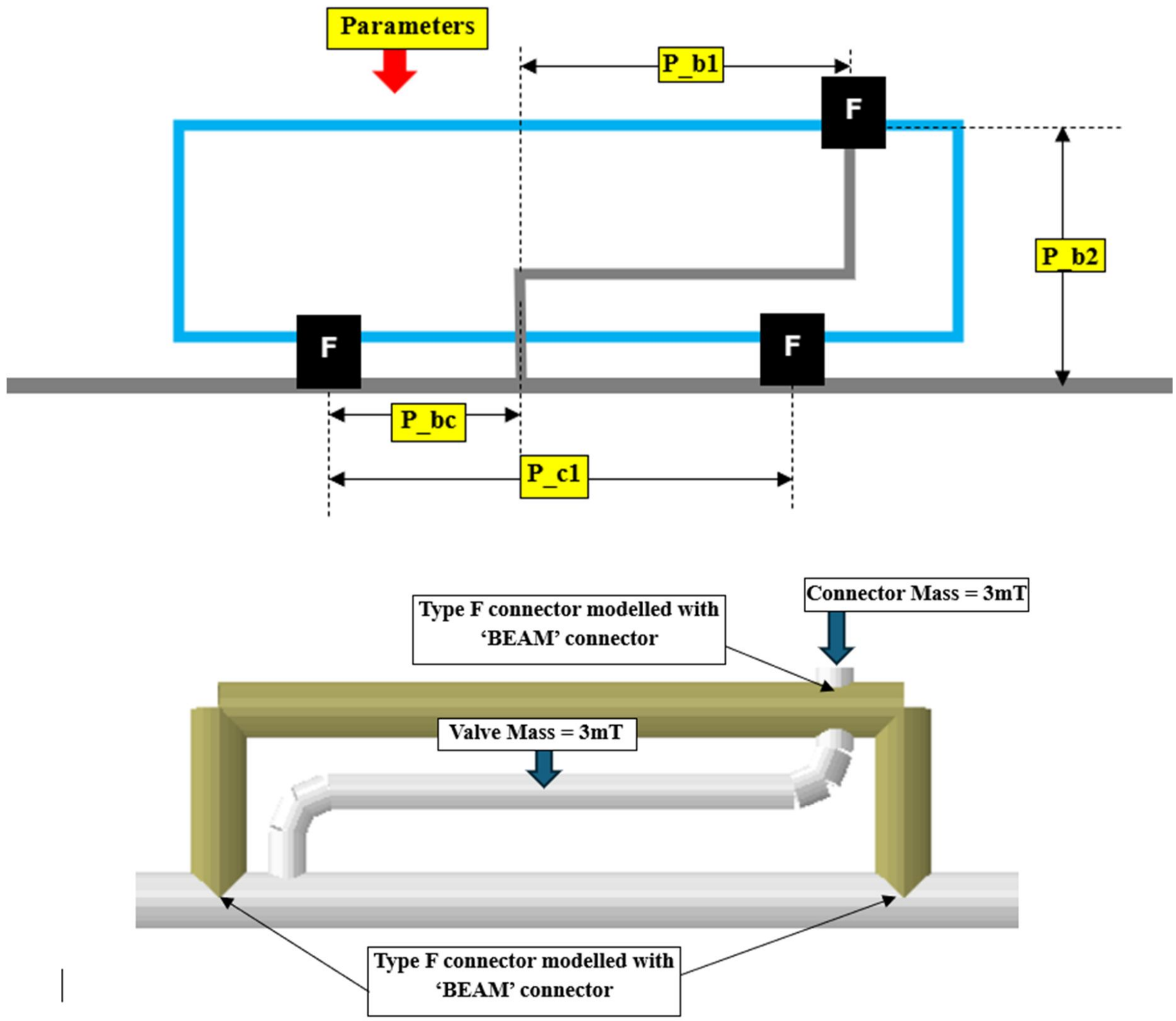

Fig. 62. Type Z-FT-F2 Layout- Analysis Model

K. Z-Branch Sliding connection to Top Structure PS: Z-FT-PS

Parameters:

Parameter	Value
	Case 1
P_b1	10D
P_b2	3.5D
P_bc	1.25D
P_c1	12.5D

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Results:

Case	Peak Strain (NE)	
	Header Pipeline	**Branch Piping**
Case 1	0.42% (At Frame connection)	0.29% (Tee outlet)

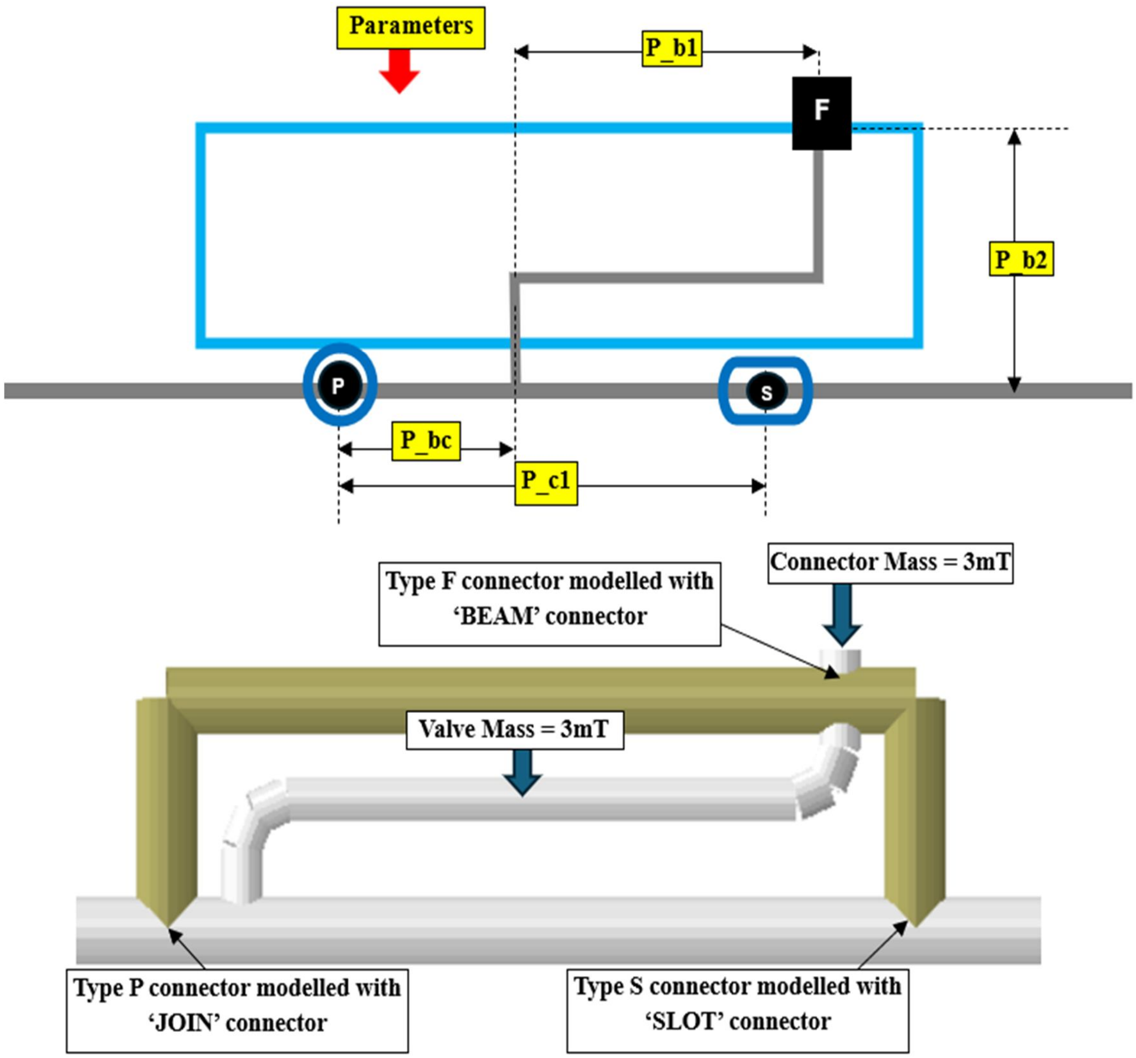


Fig. 63. Type Z-FT-PS Layout - Analysis Model

L. Summary and Findings

- Using a slot (S) connector, instead of a fixed (F) one, at the branch support lowers strain in the header and branch pipes. This held true for both the L-shaped and Z-shaped branch layouts.
- Anchoring the branch to a stiff EA-ST-F2 structure gives the lowest strain in the branch pipe itself, but it raises the strain in the header pipe at the frame connection. This shows the two connection levers act independently: the connector type at the branch support mainly governs the branch pipe strain, while the header pipe strain is governed separately by how stiff the EA-ST is and how far apart its own connection points are. A designer can therefore tune each one without strongly affecting the other.
- As with the Top and Base Structure studies, F2, F2D, PS and PSD create a lower-strain zone inside the structure that is useful for strain-sensitive parts, provided the D connector gap is controlled well.

M. Limitations and Future Work

- Connections were modelled at the pipe centreline; in practice the connector is usually carried on a boss attached to an IW-A component, offset from the pipe. This should be added in future models.
- Only the Branch fixed-to-Top Structure (–FT–) case was studied for the Z-shaped branch (Z-FT-F1, Z-FT-F2, Z-FT-PS). The Branch with Slot support to Top Structure (–ST–) case for the Z-branch (Z-ST-F1, Z-ST-F2, Z-ST-PS) was not covered here and could be completed for symmetry with the L-branch results.
- More combinations of branch geometry, connector type and support spacing should be studied.

XI. DISCUSSION

The results in Sections VII, VIII, 0 and X point to one recurring idea: where a load is applied to the pipeline matters as much as how large that load is. This is true whether the load is stiffness (Type A2), elevation (Type B2), mass, or a branch pipe load. Concentrating an effect at one or two discrete points, instead of spreading it along a length of pipe, creates a local strain spike at those points — but it can also open up a low-strain region nearby that a distributed (Type A1/B1) component cannot offer. This is the practical difference between the concentrated-parameter types studied in this paper and the distributed-parameter types studied in [1].

The connector taxonomy (F, P, S, D) gives a simple way to control this trade-off. F1 and PS connections keep the pipeline close to its plain-pipe behaviour, which is useful when the structure must not disturb the surrounding strain field. F2 connections do the opposite: they stiffen the pipe strongly at two points, producing higher local strain but also a calmer, lower-strain zone between the points that is well suited to housing strain-sensitive equipment. A deadband (the D connector) does not lower the total amount of strain in the system — it moves the strain a short distance along the pipe, away from the connection point. This redistribution is only useful if the gap size is chosen and controlled carefully; an uncontrolled gap simply moves the problem to an unplanned location.

The Base Structure behaves differently from the Top Structure under a pin-slot (PS) connection. On the Top Structure, PS keeps strain close to the plain-pipe value, much like F1. On the Base Structure, PS behaves more like F2, giving less benefit. This difference is a direct result of the base structure's shape: it carries an out-of-plane offset (parameter P_v in Figure 21) between its connection points and where it contacts the rollers, which brings in a bending effect that is largely absent from the Top Structure's in-line connection layout. This is a useful example of why a connector's behaviour cannot be assumed to transfer directly between a Top Structure and a Base Structure of the same nominal type — the surrounding geometry changes the result.

The branch piping results extend this position-governs idea to a second, independent lever. The branch pipe's own strain is set mainly by how it is attached to its support (fixed vs. slot), while the header pipeline's strain near the frame is set mainly by the stiffness and spacing of the Top Structure's own connectors to the pipeline. Because these two levers act largely on their own, a designer can lower the branch pipe strain (for example, by using an F2 support) without being forced to accept a proportionally worse header pipe strain, and vice versa. This separability is one of the more design-useful outcomes of this paper, because it means the two failure modes — branch overstress and header overstress — can, to a first approximation, be optimised one at a time rather than as a single coupled problem.

The added-mass study (Section 0) shows that distributed mass and point mass doesn’t make significant difference in the strain distribution.

Finally, it is worth restating the modelling boundary set out in Section VI: the bulkheads and other thick inline components that physically anchor a structure to the pipe were deliberately left out of every model in this paper, so that the connection-layout effect could be seen on its own. In a real design, the thick-component strain contribution characterised in [1] adds to the strains reported here at each connection point. The numbers in this paper should therefore be read as a guide to relative behaviour between connector types, not as an absolute strain a designer can take straight into a code check.

XII. CONCLUSIONS

This paper is the second in a series building an AI-assisted conceptual design framework for subsea inline structures. Together with [1], it completes Steps 1 and 2 of the seven-step programme — Component Classification and Design Intuition — for the full set of IW/EA components, by covering the concentrated-parameter behaviour types (A2, B2, C2) left open in [1], plus added mass and branch piping. Three results stand out. First, connector type is a powerful and simple design lever: F1 and PS connections leave the pipeline close to its plain-pipe strain, while F2 connections concentrate strain at the connection points in exchange for a calmer, lower-strain zone inside the structure.

Second, a deadband connector redistributes strain rather than removing it, and the outcome depends on tight control of the gap — this should be treated as a tuning parameter, not a free strain reduction. Third, branch piping strain and header pipeline strain are governed by two largely independent connection choices — the branch-to-support connector and the header structure's own connector layout — which means the two can, to a first approximation, be optimised separately during conceptual design.

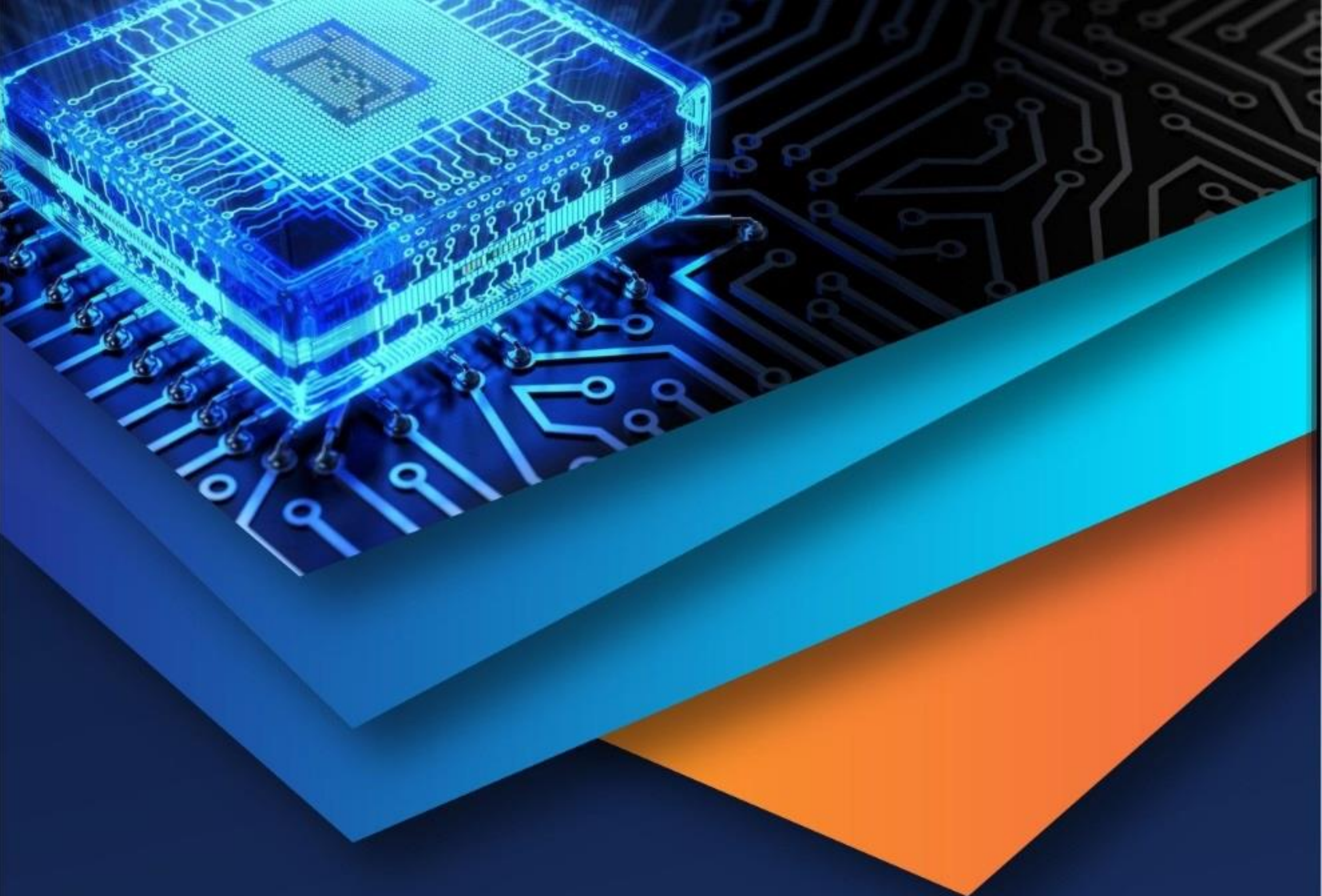
These findings extend the quantitative design intuition available for Step 3 of the framework (Intuitive Assembly), in which individual component behaviours — both the distributed types from [1] and the concentrated types from this paper — will be combined into complete, worked ILT structural assemblies.

XIII. FUTURE WORK

- Model the connector offset from the pipe centreline. Every study in this paper places connectors on the pipe centreline for simplicity; real connectors sit on a boss welded to an IW-A bulkhead, offset from the pipe. Adding this offset is the single most useful next step for turning these results into design-ready numbers.
- Broaden the parameter sweep. Each study in this paper used a small number of cases to show a trend. A wider sweep of stiffness, spacing and gap values is needed before the trends can support detailed sizing.
- Superimpose the thick-component contribution. As noted in Section VI, bulkheads and other thick inline components were intentionally excluded from every model here. A full design assessment requires adding the thick-component strain behaviour from [1] back in at each connection point.
- Proceed to Step 3 — Intuitive Assembly. With the distributed types from [1] and the concentrated types from this paper now characterised, the next paper in the series should combine them into complete, worked ILT structural assemblies, following the framework in Figure 1.

REFERENCES

[1] Sivaraman,S.M., Reddy J.V.,. “Toward AI-Assisted Conceptual Design of Subsea Inline Structures: Classification and Strain Behaviour of Inline Components During S-Lay Installation,” IJRASET, 2026



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