

## NEW APPROACHES TO THE DESIGN OF RIGID JUMPERS FOR FREESTANDING HYBRID RISERS

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### Abstract

Rigid jumpers connected to the base of freestanding hybrid risers are inherently challenging to design because they must accommodate the translation and rotation of the riser as well as the pipeline. The flexibility required to tolerate the maximum displacements usually makes them susceptible to vibration and fatigue. When the jumper will see slugging and sour service, in addition to the dynamic loads induced by the riser, the problem demands non traditional solutions.

This paper compares the traditional M-shape rigid jumper solution to 4 alternate designs. Those designs include a 3D Z-shape jumper, a centre supported V-shape jumper, an arch jumper and a soil supported jumper. Loads and other inputs are generic but realistic. The designs are sized for strength and then compared on the basis of fatigue life and recommendations are given on the suitability of each design for specific applications.

### 1. Introduction

The growth of deepwater developments necessitates the use of risers that will give good stress response and fatigue performance. The Free Standing Hybrid Riser (FSHR) is a hybrid riser solution that meets these requirements and is seeing increased use by a number of operators. The FSHR comprises of a vertical steel pipe section supported by a buoyancy tank together with a flexible pipe jumper to connect the vertical section to the host vessel. The flexible pipe jumper provides substantial de-coupling of the host vessel motion from the vertical steel pipe section decreasing fatigue damage. The FSHR also requires a subsea rigid jumper to connect the vertical steel pipe section to the associated pipeline.

To date most FSHR rigid jumpers are M-shaped and designed for vertical end connectors. This configuration allows for the riser base motion to be handled and can accommodate changes in length during fabrication to account for the as-installed structure positions. Furthermore they can be installed through a relatively simple deployment process. However a number of issues can arise with their design which may necessitate the selection of an alternative configuration. These include excessive Vortex Induced Vibration (VIV), susceptibility to fluid slugging fatigue damage, unacceptable FSHR induced fatigue and the need to accommodate complex end connection angular alignment. The relative features and merits of 4 alternative configurations to the conventional M-shape rigid jumper for a typical 12 inch outer diameter production FSHR in 2000m of water depth are presented.

### 2. Layout and Material Requirements

A comparison of the material requirements for the different rigid jumper configurations is presented in Table 1. The pipe material selected is of 12.75 inches outer diameter with a wall thickness of 27mm and a minimum yield strength of 65ksi. The different configurations are shown in Figure 1 for comparison and sized to give a similar strength response. Note that some variations in strength response may be observed in this paper as a limited number of extreme loading cases are presented. Fatigue response at the pipe weld locations is evaluated considering F2 curve details with

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an associated SCF of 1.4 on the OD. Production duty is assumed with the jumper conveying typical multi-phase hydrocarbons.

Table 1. Material Requirements – Comparison

Parameter	M-Shape	Z-Shape	V-Shape	Seabed Supported	Arch
Length of Straight Pipe	53m	53m	38m	55m	24m
Number of Bends	6	6	7	7	1
Total Curvilinear Length	73m	73m	61m	91m	63m
Hub-to-hub Distance	38m	31m	22m	52m	25m
Overall Length	38m	30m	20m	28m	25m
Overall Width	-	8m	8m	36m	-
Overall Height	16m	16m	16m	18m	29m
Bend Sizes	5 x OD, 90°	5 x OD, 90°	5 x OD, 90°	5 x OD, 90° 5 x OD, 40° 20 x OD, 90° 20 x OD, 60° 20 x OD, 40°	25m, 180°
Additional Requirements	-	-	Additional support structure	-	-

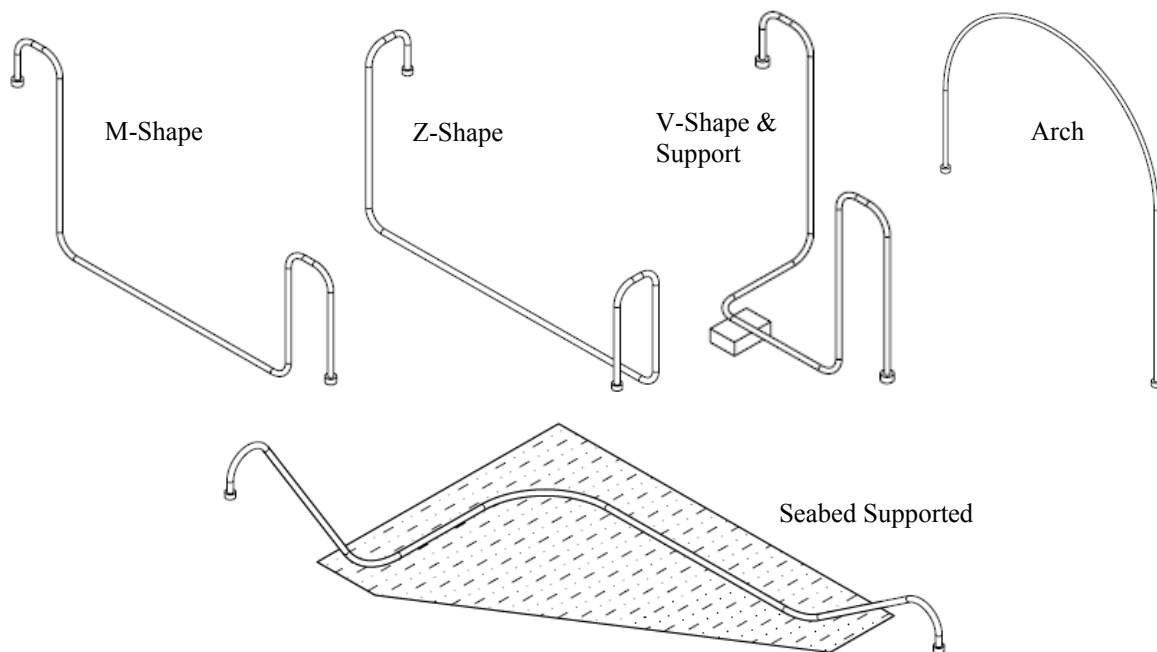


Figure 1. Rigid Jumper Configurations

### 3. Response

During the design process the response of the rigid jumper should be evaluated when subject to loads from a number of sources. These loads can be categorised as either extreme loads (or storm loads) or fatigue loads. Table 2 presents a number of these loads together with other design considerations. The design must also consider the level of uncertainty inherent in some parameters associated with these loads and the configuration of the design itself. These potential uncertainties include for example metrology tolerances, fabrication tolerances and soil characteristics. Compromises may have to be made between the load response, fabrication considerations and transportation and installation requirements. In the following sections the response of each of the rigid jumper configurations proposed is presented and the results compared in Section 3.7.

Table 2. Loading Considerations

Extreme Loading Considerations	Fatigue Loading Considerations
Riser Base Rotation	Vortex Induced Vibrations (VIV)
Pipeline Expansion	Riser-induced Vortex Induced Motions (VIM)
Local Bend Thinning	Riser-induced First-order Motion
Wall Thickness Tolerance	Riser-induced Second-order Motion (Vessel Drift)
Internal Sacrificial Corrosion Allowance	Riser-induced VIV
Pipe End Machining	Pressure and Temperature Variation
High Temperature Material Yield Strength De-rating	Slugging / Flowline Induced Pulsation
Internal and External Pressure	
Tolerances (installation, fabrication, etc.)	

### 3.1. Riser-induced Extreme Loading

Due to environmental loading (current and vessel offset), the FSHR buoyancy tank will displace laterally and rotate the flexible joint beneath the lower riser assembly, Figure 1. With a current speed of around 1m/s at the buoyancy tank elevation, the top of the FSHR may displace approximately 95m and rotate at the riser base by approximately 10 degrees. The response of the different rigid jumper configurations to this extreme environmental loading is compared for two cases: with the riser leaning towards the end connector (putting the rigid jumper into compression) and with the riser leaning away from the rigid jumper, Figure 2. The resulting response of the rigid jumpers is shown in Table 3. Connector loads are observed to be highest with the Arch configuration, at both ends of the jumper, and lowest for the Seabed Supported configuration. The loads obtained with the Z-Shape are lower than with the M-Shape, which is due to the increased flexibility inherent in the Z-Shape configuration.

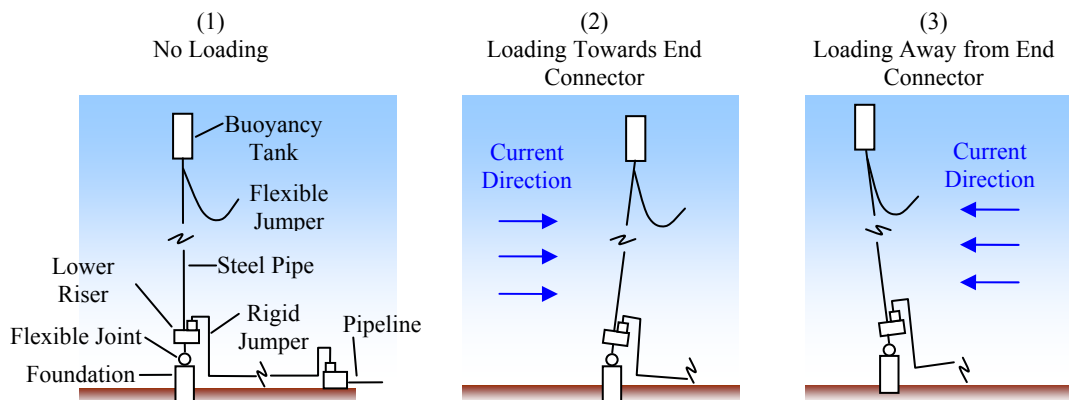


Figure 2. Extreme Loading Definition

Table 3. Rigid Jumper Response to FSHR Extreme Loading

Loads	M-Shape	Z-Shape	V-Shape	Seabed Supported	Arch
Maximum Von Mises Stress Along Jumper (MPa)	202.8	200.5	222.3	102.8	252.3
Bending Moment at Riser End Connector (kNm)	332.3	271.0	251.2	148.2	423.0
Torque at Riser End Connector (kNm)	12.6	10.5	31.7	12.1	0.1
Bending Moment at Pipeline End Connector (kNm)	135.6	125.8	132.7	39.6	339.2
Torque at Pipeline End Connector (kNm)	23.2	35.0	53.8	2.2	0.0

### 3.2. Rigid Jumper Slug Loading

There are two primary phenomena caused by internal fluid slugging that can be responsible for fatigue damage of a rigid jumper carrying multi-phase fluids. Firstly the changes of internal fluid weight cause a gross change in the deflected shape of the rigid jumper. Secondly there is a change of the inertial force on each rigid jumper bend as each

slug enters and exits. The rigid jumper fatigue response is determined for a typical slugging regime consisting of a slug density of 533kg/m<sup>3</sup>, a velocity of 8.0m/s, a length of 150m, at a frequency of 160slugs/hour. The change of internal fluid weight and inertial force due to the passage of each slug are developed and timetraces of the resulting vertical and lateral forces at each node generated. These force timetraces are applied to the rigid jumper model in a transient finite element analysis and fatigue damage is calculated using a rainflow counting approach. It results that a pipe with long unsupported sections and high flexibility will be subject to high damage when subject to gross internal fluid weight variations, whilst a rigid jumper with tight bends will be subject to high fatigue damage caused by higher changes in inertia loading (due to the more abrupt change in fluid direction). Representative rigid jumper fatigue response to slugging is shown in Figure 3.

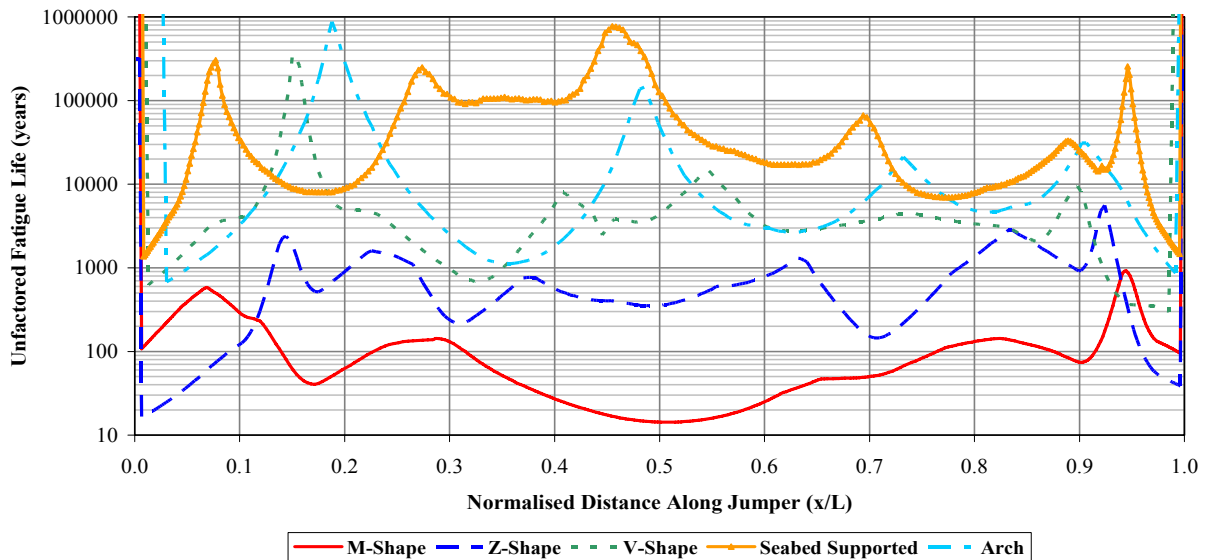


Figure 3. Slugging Fatigue Loading

### 3.3. Rigid Jumper VIV

Rigid jumpers may be subject to VIV due to near-seabed currents. As the more probable low speed currents induce higher cut-off periods, the induced fatigue damage is expected to be higher on systems with high modal periods. Table 4 presents a comparison of the modal response of the rigid jumper configurations considered. It can be observed that the M-Shape rigid jumper has the highest modal periods. Higher damage is therefore expected when considering this design. On the other hand, VIV will generate lesser damage on the seabed supported and V-Shape rigid jumper options as these have much lower modal periods. If rigid jumper VIV is a major concern, it is possible to fit VIV suppression strakes to the rigid jumper to reduce the excitation.

Table 4. Rigid Jumper Modal Response

Mode Number	Modal Period (s)				
	M-Shape	Z-Shape	V-Shape	Seabed Supported	Arch
1	10.068	4.166	2.527	2.153	3.719
2	4.400	3.198	1.498	2.071	1.701
3	3.796	1.899	1.086	1.996	1.333
4	1.533	1.529	0.853	1.925	0.626
5	1.529	1.181	0.620	1.860	0.601

### 3.4. Riser-induced VIV Loading

A rigid jumper may also be prone to fatigue damage due to the VIV of the FSHR through the connection at the base of the system. When looking at riser-induced VIV motions, fatigue damage is expected to increase for the designs whose modal period is within the range of natural periods of the riser itself. If the rigid jumper can resonate at a period at which the FSHR may also be resonating due to VIV the resulting damage in the rigid jumper will be increased. The rigid jumper natural periods shown in Table 4 can be compared to the response of the FSHR, Table 5. It can be observed that the M-Shape rigid jumper has the highest modal periods which also come within the range of the FSHR periods. Higher damage is therefore expected when considering this configuration. Conversely riser VIV will generate

lesser damage on the seabed supported and V-Shape rigid jumpers as these have much lower modal periods. This observation has been further qualified by riser-induced VIV fatigue analysis.

Table 5. FSHR Modal Response

Mode Number	Modal Period (s)	Mode Number	Modal Period (s)
1	204.1	9	7.2
2	48.3	10	6.5
3	26.0	11	5.8
4	17.6	12	5.2
5	13.3	13	4.8
6	10.7	14	4.4
7	9.0	15	4.1
8	7.9		

### 3.5. Flowline-induced Pressure and Temperature Cyclic Loading

Under variations of internal fluid, pressure and temperature, the adjacent pipeline will experience several cycles of expansion and contraction which will generate displacement of the rigid jumper end connection. In order to assess the implications of this cyclic loading on the rigid jumper response, an assessment is performed considering a maximum pipeline expansion range of 1.2m and 38 cycles per year. It should however be noted that, depending on the installation process of the pipeline end connection, such case may not be realistic, but offers a good comparison of the respective jumper performances. The rigid jumper response is shown in Figure 4. Configurations with lower flexibility, such as the M-Shape, are observed to be subject to higher levels of damage. The seabed supported configuration also experiences higher damage, due to seabed friction, while the arch design offers an improved fatigue response.

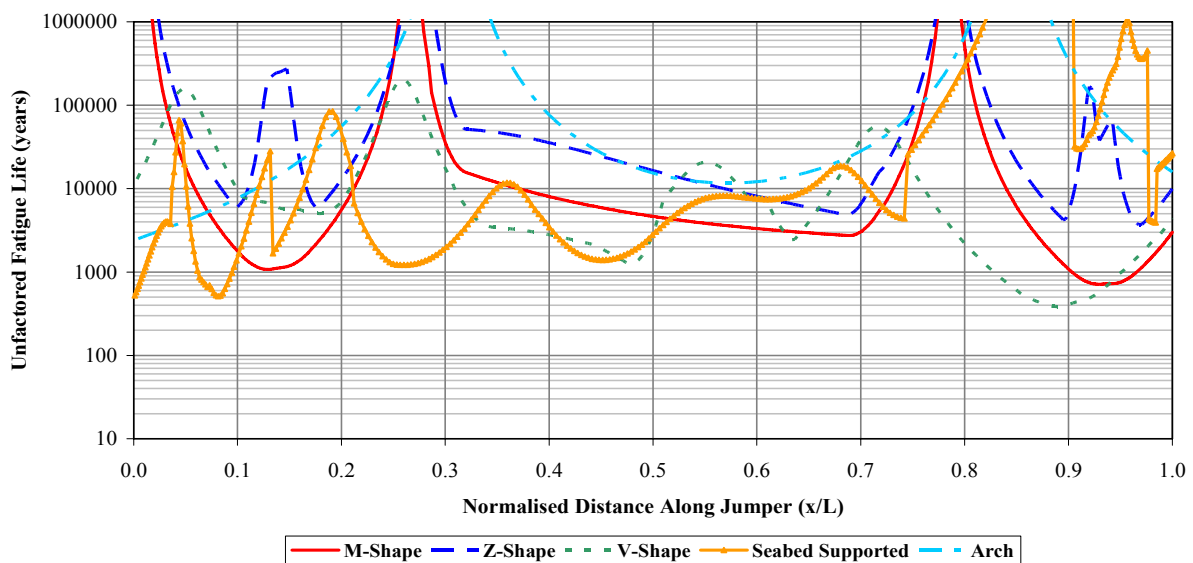


Figure 4. Pressure and Temperature Fatigue Loading

### 3.6. Other Riser-induced Loading

This section covers the effects of FSHR vortex induced motions (VIM) and second-order fatigue (vessel drift), which induce displacement of the riser. The effect of this loading is approximated via a sinusoidal displacement of the buoyancy tank of 5.5m at a period of 200s, and the resulting fatigue damage in the rigid jumper is shown in Figure 5. It should be noted that first-order fatigue effects (wave induced loading), which is also a riser induced effect, cannot be similarly represented as the resulting displacement of the riser is unlikely to be purely sinusoidal. The results presented in Figure 5 are however indicative of wave-induced loading but a dedicated assessment should be performed when conducting a detailed design. The response of the V-Shape jumper configuration is observed to be more onerous, due to the interaction with the support, while the arch configuration experiences reduced damage, its shape being particularly suitable to withstand this source of loading. The minimum fatigue lives along the length of the rigid jumpers is shown in Table 6.

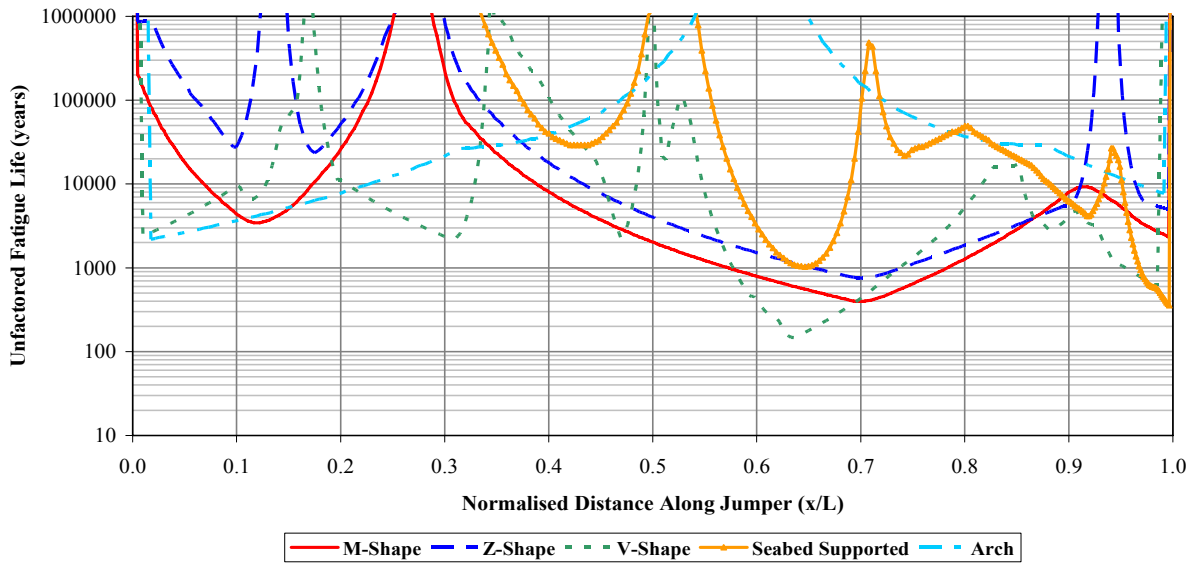


Figure 5. Riser Induced Fatigue Loading

Table 6. Rigid jumper Response to Fatigue Loading – Comparison

Fatigue Source	Minimum Fatigue Life Along Rigid Jumper (Years, Unfactored)				
	M-Shape	Z-Shape	V-Shape	Seabed Supported	Arch
Slugging	14	16	300	1,374	681
Pressure & Temperature	713	3,705	384	514	2,507
Riser Induced	398	751	147	358	2,189

3.7. Conclusions

A comparison of the overall behaviour of the different rigid jumper configurations is given in Table 7. Configurations which exhibit increased flexibility, such as the Z-shape, are observed to generate lower connector loads but can also be more sensitive to fatigue. The Seabed supported configuration is shown to offer a good compromise between strength and fatigue response.

Table 7. Performance of Rigid Jumpers – Summary

Jumper Configuration	Strength	Fatigue
M-Shape	Good strength response due to high flexibility.	Sensitive to VIV – potential need for suppression strakes. Sensitive to slugging – inertial loading is onerous, which could increase welding requirements.
Z-Shape	Better strength response and lower end connector loads than M-Shape due to increased flexibility.	Similar issues to M-Shape. Length can be further reduced, but limited by minimum achievable distance between end connections.
V-Shape + Support	Similar response to Z-Shape. Torque loading increases in connectors due to higher out-of-plane loading.	Sensitive to VIV – potential need for suppression strakes. Sensitive to slugging – weight variation effects are reduced but inertia variation remains dominant. Less sensitive to VIV due to less floating sections. Slugging weight variation effects dampened by soil. Inertia variation effects reduced by selection of larger radius bends.
Seabed Supported	Good strength response. Reduced connector loading.	Increased damage from FSHR induced fatigue effects (VIM, FOF, etc.) due to loss of flexibility induced by soil. Better response to riser-induced VIV as first modes of the rigid jumper have much higher frequencies than that of the FSHR.
Arch	Acceptable strength response. High connector loads	Potentially more difficult to add VIV suppression strakes. Improved slugging response. Low sensitivity to riser-induced fatigue.

## **4. Other Design Considerations**

A number of uncertainties and tolerances must be considered during the design of a rigid jumper. Some of these are discussed in the following sections.

### **4.1. Installation Tolerance**

The installation of the pipeline end termination assembly and FSHR to which the rigid jumper will connect will be achieved to a certain level of accuracy. This tolerance can be lateral and angular. As the actual location of the end connections will not be known before the as-installed metrology is performed, a range of end-to-end connection distances must be evaluated for the design which will result in a range of rigid jumper sizes, all of which must meet the loading criteria discussed above.

### **4.2. Fabrication Tolerance**

The fabrication of the rigid jumper will be performed to a certain level of dimensional accuracy. This means that the final installed rigid jumper may differ in size to that actually requested from the fabricator. This difference will mostly result in increased loading on the end connectors as the male and female parts will not be a perfect fit and a certain level of deformation will be induced into the rigid jumper to achieve make-up. The resulting increase in loading must be evaluated during the design process to ensure that the capacity of the rigid jumper pipe, end connectors, and the adjacent structures is not exceeded.

### **4.3. Metrology Tolerance**

As mentioned above the final dimensions of the rigid jumper will be based upon the as-installed positions of the adjacent structures obtained through metrology. This metrology will be subject to a tolerance and this inaccuracy may result in a load increase which must be evaluated during the design process to ensure that the capacity of the rigid jumper pipe, end connectors, and the adjacent structures is not exceeded.

### **4.4. Stack-up Tolerance**

The adjacent FSHR will have a set of design and fabrication tolerances that will generate differences from the nominal configuration assumed for the design of the rigid jumper. Such tolerances can relate to the amount of up-thrust generated by the buoyancy tank at the top of the riser, the initial position of the vessel, the weight of the vertical pipe string etc. This may result in the location of the rigid jumper connector at the FSHR end differing from initial assumptions. Further consideration should therefore be made during the design phase to ensure that the rigid jumper remains fit-for-purpose.

### **4.5. Installation Conditions**

A running tool will be installed along with the rigid jumper to allow stabbing and connection of the two parts of the jumper end connections. This tool usually has a cone to “capture” the male part of the connector if it is not directly located below the female part. The size of this cone sets the maximum separation which is allowed between the two halves of the connector during installation and can therefore be used to determine how much relative displacement may be allowed. This permits the determination of an installation window for the connection of the hub in terms of FSHR motion.

### **4.6. Soil Strength Profile**

Soil profiles can be predicted, to an extent, based upon measurements taken in the field. However the long-term behaviour of the soil is still somewhat unpredictable. It is usually required to determine the amount of settlement of mud-mats and other seabed supported components, for which lower and upper bound values may be determined.

For the design of a seabed supported rigid jumper, the interaction between the jumper pipe and the soil is at the heart of the design. Over the life of the field, the rigid jumper is likely to experience significant vertical motion at the soil interface induced by the FSHR, as well as horizontal motion as a result of the expansion of the flowline. As such, the pipe may form a trench in the soil creating resistance against lateral motion. An estimate of these effects should be accounted for during the design of the rigid jumper.

### **4.7. Slugging Profile**

Slugging could generate significant fatigue damage in the rigid jumper. In order to assess this, slugging profiles must be determined based on the expected fluid contents and production rate. Predictive models do exist to generate these profiles but they may be subject to a significant level of uncertainty when predicting the fluid contents and production rate for the complete field life. Similarly, during the life of the field the flow rate may have to be modified to optimise production. This could lead to a different rigid jumper response to that initially predicted.

#### **4.8. Impact of Strakes**

Rigid jumpers are likely to be sensitive to VIV. In order to ensure that this does not result in unacceptable fatigue damage, suppression strakes may be considered. The effect of these strakes on the response of the rigid jumper should be investigated.

#### **4.9. Modelling / Analytical Considerations**

Further considerations should be made with regards to how the rigid jumper finite element model is generated and the analysis is performed. The use of a coupled FSHR/rigid jumper model is highly recommended as the rigid jumper response is driven mostly by riser loading but the rigid jumper stiffness can affect the response of the base of the FSHR. This can also dictate the choice of design code for the assessment. Potential added strength from any corrosion resistance alloy clad to the pipe bore could also be considered. The current approach is generally not to account for any added strength from the clad material for simplicity and conservatism. However with more stringent design requirements considering the benefits of the clad material could be highly beneficial. However adequate demonstration should be obtained to justify this approach before commencing design activities. Finally detailed soil modelling may be required for designs which interact with the seabed. These must provide correlation between friction (axial and lateral), trenching and remoulding of the soil through the field life.

### **5. Fabrication**

The main challenges to fabrication for each of the rigid jumper configurations are detailed in the following sections. Note that different configurations may necessitate different welding requirements depending on how fatigue sensitive the design will be. Higher fatigue loading will demand better weld classifications, reduced stress concentration factors (SCFs), tighter Hi-Lo requirements whose cost must be considered when comparing different rigid jumper configurations. The number of closure welds required on a rigid jumper may also vary between configurations.

#### **5.1. M-Shape Design**

An M-shape rigid jumper usually consists of two arches, one at each end, that provide flexibility and a main section of pipe, the span, to accommodate the variation in length between the two end connections. The configuration requires the manufacture of six 90degrees bends with the radius of the bends normally dictated by pigging requirements.

The primary fabrication concern with this configuration of rigid jumper is the necessity to accommodate angular variations of the end connections – i.e. when the connectors are not perfectly vertical. This can be as a result of the installation tolerance of the flowline end termination assembly in addition to the verticality of the FSHR. With an M-shape rigid jumper such angular variations can only be effectively dealt with in one plane and different fabrication procedures may be sought to ensure that all angles can be accommodated. This may include the use of mitre welds. However the introduction of a mitre in the design may induce additional weld procedure qualifications as well as reduced fatigue performance. Alternatively the design may remain unchanged and these angular variations could be included by just considering the increase in loading resulting from deformation during the installation.

#### **5.2. Z-Shape Design**

A Z-Shape design is based on the same principle as the M-Shape. However, where the M-shape is maintained within a single plane, the Z-shape will effectively be three-dimensional with its arches being set at 90degrees from the main span and can therefore accommodate angular variations of the end connectors in all degrees of freedom.

#### **5.3. V-Shape Design with Centre Support**

The main objective of this configuration is to add a further bend out of the connector-to-connector direction, where the main loading is expected, in order to increase further the flexibility. This configuration requires a further external support structure to be added. This structure must be such that contact with the rigid jumper must be maintained most of the time, albeit not some extreme storm events. Considerations must be made about the position of this structure, with respect to the jumper, its elevation and the associated tolerances.

#### **5.4. Arch Design**

This configuration is based on either a single bend, at 180degrees, or two 90degrees bends connected with a straight section which ensures that length variation between the hubs can be accommodated. The main challenge of this configuration is to manufacture a bend of such a size (~12.5m radius), while maintaining minimal ovality through its section. However it involves a reduced number of welds (3 or 4) when compared to other configurations (over 10 for an M-Shape design).

### 5.5. Seabed Supported Design

This rigid jumper configuration is similar to the V-Shape except that the centre support is now replaced by the seabed. As a result the length of the jumper is increased to ensure that it does not come close to contact with any of the adjacent structures before reaching the seabed. As this is a similar three dimensional structure to the V-Shape design its manufacture poses no further challenges but does require an increased length of pipe. The number of close-out welds will also be increased as its dimensions will be based not only on the distance between the two connectors but also the metrology of the seabed as contact with the soil must be ensured at all times. Higher accuracy of seabed bathymetry will also be required in order to ensure adequate seabed contact.

In order to decrease the length of pipe required, alternative bend designs may be required, such as increased bend radius (20D vs. 5D) or reduced bend angles (e.g. 30degrees).

## 6. Transportation & Installation

All the rigid jumper configurations apart from the Arch are typically transported in their as-installed orientation with the end connectors supported by dummy hubs. The Arch configuration should be laid flat due to its increased height. The M-Shape configuration also offers the ability to be laid flat should the need arise. The V-Shape and Seabed supported configurations add a further demand in that they respectively require an additional structure to be transported and have a much larger footprint, both of which increase space requirements on the transportation vessel. Table 8 shows a comparison of the different rigid jumper designs from an installation perspective.

Table 8. Installation of Rigid Jumpers – Comparison

Jumper Configuration	Advantages	Disadvantages
M-Shape	Simple spreader bar design required. Rigid jumper remains balanced underwater.	If transported flat, potentially difficult to lift to the installed orientation.
Z-Shape	Relatively simple spreader bar design required.	Need to lift the rigid jumper above the dummy hubs on the transportation barge.
V-Shape + Support	-	Support structure to install. Potentially congested seabed. More complex spreader beam design. More complex spreader beam design.
Seabed Supported	-	Increased jumper height makes lifting more difficult. 3 points of contact during installation (2 end connectors and seabed)
Arch	Rigid jumper remains balanced underwater. Relatively simple spreader bar design required.	Need to lift to the installed orientation as transported flat. Bottom currents could cause installation difficulties due to the high elevation of the arch.

## 7. Long Term Integrity

A number of time dependent issues such as settlement of the adjacent structures adjacent are generally assessed during the design phase. However a number of other changes may arise that cannot be accurately predicted during the design phase. A significant concern for example lies with the integrity of the soil for a seabed supported rigid jumper. During extreme storm events a trench is expected to form under the seabed supported pipe section. The extent of this trench is difficult to predict but can be conservatively determined. However the jumper is expected to re-assume a pre-trenched position once the loading reduces with the soil slowly remoulding below the pipe with time. The remoulded soil could have a different strength to that initially assumed and therefore the behaviour of the rigid jumper may vary over the field life. If a rigid jumper configuration requires the use of an additional support structure, consideration must similarly be made with regards to its long-term behaviour including for example settlement and degradation. Installation of a structural monitoring system is recommended to capture any changes in response alongside regular visual inspection of the seabed or support structure conditions.

As rigid jumpers may be fatigue sensitive remedial solutions may be sought during the field life in preference to ensuring very high performance welding. One option would be to replace the jumper after a per-determined period of time. This will obviously involve further manufacture, transportation and installation, but may also require a different rigid jumper to be installed, as the conditions during this new installation may differ from the initial ones.

## 8. Recommendations / Conclusions

A comparison between the different rigid jumper configurations presented is shown in Table 9. From a design perspective, the rigid jumper configuration must be selected as a compromise between flexibility, resistance to riser induced loads, pipeline expansion, VIV excitation and slugging. Furthermore full consideration should be given to fabrication, transportation and installation aspects. For many applications a traditional M-shaped rigid jumper may be suitable but for more demanding applications a Z-shape or seabed supported configuration could be considered but these do add additional design and fabrication complexity. Full consideration of long term integrity should also be considered at the design stage especially for more complex configurations.

Table 9. Overall Comparison

Jumper Configuration	Advantages	Disadvantages
M-Shape	Simple concept. Proven strength response.	Fatigue sensitive esp. slugging leading to possibly need for high quality welds. VIV damage potentially large, however strakes can be accommodated. End connection angular tolerances can be difficult to accommodate. High loading on end connectors.
Z-Shape	Increased flexibility with an improved strength response. End connection angular tolerances easy to accommodate.	Fatigue sensitive esp. slugging leading to possibly need for high quality welds. VIV damage potentially large, however strakes can be accommodated.
V-Shape + Support	Increased flexibility with a similar strength response to the Z-Shape configuration. Improved slugging response.	Slug inertial loads can still provide high levels of fatigue damage. VIV damage potentially large, however strakes can be accommodated. Support design required together. Need to ensure long term integrity.
Seabed Supported	Improved fatigue response – VIV damage lower than other designs. Good strength response. Increased damping due to soil interaction.	Increased pipe length requirement. Fatigue response dependant on soil response. Increased complexity of transportation and installation. Higher torque loading on end connectors. Increased number of closure welds.
Arch	Robust fatigue life. Simple design.	Possible manufacture and installation issues. Higher end connector loads. Not currently field proven. VIV damage cannot be mitigated by strakes.