# Temporary Works Toolkit

## Part 14: Lifting, moving and jacking

**The Temporary Works Toolkit is a series of articles aimed primarily at assisting the permanent works designer with temporary works issues. Buildability – sometimes referred to now as 'construction method engineering' – is not a new concept and one always recognised as vital to the realisation of one's ideas; it ought to be at the forefront of an engineer's mind.**

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### Introduction

This article provides a brief introduction to some of the construction techniques of lifting, moving and jacking that may be needed to build more challenging permanent works, particularly when installing large or heavy prefabricated elements.

The article discusses cranes, self-propelled modular transporters (SPMTs), slides and launches, and jacking, with the pros and cons of each technique considered.

### Building off site

There is a growing trend for off-site prefabrication, with a number of reasons why building off site may be preferable to building *in situ*:

- It may be safer to build elsewhere, e.g. to avoid building at height or over water.
- Off-site prefabrication will reduce the amount of temporary works required on site.
- There may not be foundations and working space available beneath the structure, e.g. in rivers, over valleys, on poor ground, or above roads, railways, sewers and tunnels.
- The construction may cause disruption to adjacent sites, e.g. when working near or over railways.
- There may be unsuitable or no working space, e.g. on a congested city centre site.
- There may be a limited period of access to the site, e.g. rail possession, tidal working.
- There may be obstructions, e.g. something already on site, especially if an existing structure is being replaced.
- Off-site prefabrication may allow an improvement in programme delivery, e.g. working on different parts of the project concurrently.
- Building off site provides protection from the environment during fabrication.

However, off-site prefabrication increases the size and weight of elements that need to be transported and installed.

### Key questions

Whenever something needs to be lifted, tilted, pushed or pulled, there are some common questions that should be asked:

- What is the size, weight and position of the centre of gravity (CoG)?
  - The point of application of the lift must pass through the CoG, or movement will take place; the load will slew, twist or rotate.
- What are the direction, distance and height to be moved? Are there changes in direction of travel and slope or fall?
- Does the load have to be tilted?
- What is the construction of the load to be moved?
  - What is its strength and rigidity?
  - How is it supported before moving?
  - What is the relative movement between supports?
  - What is the location of attachment points?
  - What is the maximum reaction at each attachment point?
- Will load be transmitted through two, three or four points?
- How will the load be supported after placing?
  - Will it be supported immediately, without the need for grout to set?
  - It must be lined and levelled accurately.
  - Temporary supports must have adequate strength and stability for all ongoing environmental and construction loads, e.g. accidental impact, wind and hydrostatic concrete loads, until incorporated into the permanent works.
- What are the site conditions?
  - What are the ground conditions, topography and foundation requirements?
  - Are there constraints from adjacent sites, such as headroom near airports, over railways or near nuclear facilities?
  - What is the route of transportation? Delivery by road may impose limitations, although this is less of a problem if delivering by river or sea.
  - On-site assembly of subassemblies constructed off site may be required.
- How many items need to be moved, e.g. one-off move or multiple items?
- Is speed critical (both programme duration and velocity)?
- Are there environmental constraints, e.g. weather, tide, season?
- What provides the failsafe in case of malfunction?
- Is there any novelty in the design of the permanent works which makes its temporary support particularly difficult

(e.g. the current fashion for structures with apparently unsupported cantilever sections)?

For safe and efficient construction, the methodology should always be considered as part of the permanent works design (see Part 13 of this series[1]). Planning the method of construction can be complex. There will always be more than one way to build something; some ways will be more efficient in terms of cost, resources and programme (while maintaining the requirements of safety and quality of the completed works) than others.

The goal is to find the most effective and efficient way. This aim for efficient constructability also drives innovation in supply, installation, material technology and construction plant. All other things being equal, this will give the best means of meeting the client's requirements, whether they be lowest built price, quickest programme or least disruption to stakeholders. (The lowest-price permanent works solution may not be the cheapest, fastest, least disruptive or safest to build.)

## Cranes

In the 1970s, a 30Te mobile crane would have been considered large. Today, a 120Te mobile crane would not be unusual and mobile cranes up to 1200Te are available for hire. Construction techniques have changed and developed with the size of crane available, and the demand for bigger and further lifts has driven the development of larger cranes.

There are a number of types of crane, including:

- mobile cranes
- crawler cranes
- hoists
- derrick cranes; shear legs
- tower cranes, which can be:
  - static
  - mobile
  - rail mounted
- portal cranes
- ring cranes.

Most cranes consist of a hook block, jib, winch, slewing ring, counterweight, chassis supported on wheels, tracks or outriggers, and foundations.

Cranes with a jib and counterweight rely on overturning and restoring moments. When lifting an object, the crane tips forward onto the supports (e.g. outriggers, wheels or tracks) closest to the load. To prevent overturning, a counterweight provides a larger restoring moment. The centre of gravity of the whole arrangement moves 'forwards' – the supports nearest the load have the highest reaction and those furthest away take a smaller share.

When unladen, the counterweight pulls the crane 'backwards' and the supports under the counterweight have the highest load.

The arrangement of supports is typically in a square so that the lifting duties are equal in all directions.

The largest of cranes have a 'superlift' – an additional counterweight comprising a rear boom connected to separate kentledge, which can be substantially heavier than the lifted item. To avoid this pulling the crane over backwards, it is set down on the ground when not in use.

Pros and cons of cranes are presented in Table 1.

### Mobile cranes

Mobile cranes (Figure 1) include wheeled telescopic boom cranes, rail cranes, mobile tower cranes, crawler cranes (Figure 2), loader cranes ('HIABs'), telescopic forklifts and spider cranes.

Wheeled cranes are usually road going, can make their own way to site and, generally, take less time to rig. Larger mobile cranes are delivered in several vehicles and rigged on site. Crawler cranes have to be delivered to site on transport, then rigged.

Crawler cranes can travel with a load on the end of the hook. Mobile cranes usually cannot travel, or if they can, have very reduced duties.

Rail-mounted cranes are very specialist pieces of equipment. The support positions are not symmetrical so lifting duties vary with jib direction.

Mobile and crawler cranes require access to the site and land around the structure from which to work. In heavily built-up areas, or on large-span bridges, this is not available so other solutions are used, e.g. hoists, derricks and tower cranes.

### Hoists

Hoists attached to runway beams supported by a scaffold set over the construction have long been used to lift pieces into place. A historical article in the *Proceedings of the Institution of Civil Engineers* shows this method being used to build Nelson's Column in London (Figure 3)[2].

**Figure 1** Examples of mobile crane


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**a) Newbury Racecourse rail bridge, Berkshire: 550Te crane with 150Te superlift, 185Te outrigger load, lifting 96Te at 33m**


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**b) Richmond Street bridge, Ashton-under-Lyne: 800Te crane with 300Te superlift, 245Te outrigger load, lifting 12Te at 66m**


SKANSKA BAM, SEVERFIELD

**Figure 2** Crawler cranes performing tandem lift for Ordsall Chord rail bridge, Manchester: 1350Te and 750Te crawler cranes tracking and slewing with 600Te load; track bearing pressures 600Te/m²; 600Te superlift

**TABLE 1: PROS AND CONS OF CRANES**

| Pros | Cons |
|---|---|
| Most commonly used solution – benchmark against which other solutions are compared | Can't be used in high winds |
| | Foundations required – can be quite large |
| | Headroom restrictions – near flightpaths or when lifting under something |

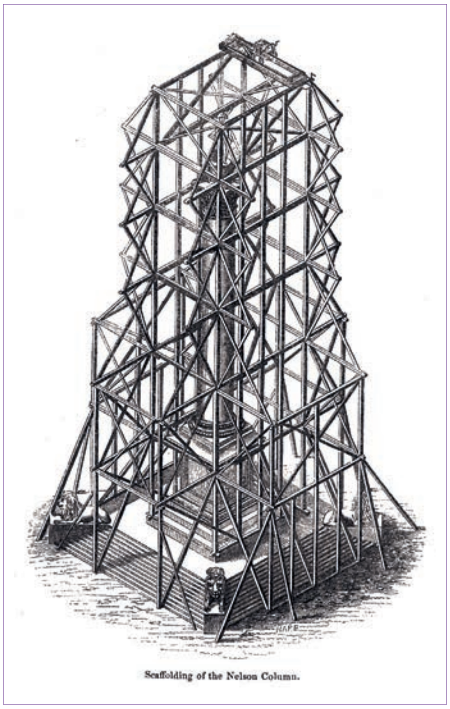


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**Figure 3**
**Scaffolding used to erect Nelson's Column, London, 1844**[2]

### Derricks

The term 'derrick' refers to any crane consisting of a mast which projects over the load and is tied back to a foundation. Derricks have been used on the segmental construction of cantilever structures, e.g. arch suspension bridges. The crane is attached to the abutment and used to lift the components of the next section into position. When this part of the structure is secure, the crane is dismantled, moved forwards and re-erected at the end of the structure. This technique is still used today for the construction of balanced cantilevered bridges, such as the Queensferry Crossing, Edinburgh (Figure 4).

### Shear legs

Shear legs, related to the derrick, have two legs forming an A-frame. Shear legs in combination with strand jacks were used to great effect when raising the London Eye observation wheel (Figure 5).

### Tower cranes

Tower cranes incorporate a mast (Figure 6). Jib types include horizontal (trolley and flat top), luffing, goose neck and jack knife.

Such cranes are designed for operating duties at working wind and out-of-service conditions. To reduce the effects of the out-of-service wind moment, it is common to permit the jib to blow in the wind like a weather vane. The length of jib with the greatest wind moment rotates downwind, so the counterweight faces the prevailing wind and the counterweight moment opposes the wind moment.

Depending on space and ground conditions, tower crane foundations can be mass-gravity bases or piled, the piles resisting the compression and tension produced by the overturning moments. Tower crane bases are often incorporated within the footprint of the permanent structure – inside lift shafts is a favourite place.

Where the crane oversails sensitive areas, e.g. nuclear sites or railways, it may be a requirement to down-rate the crane capacity.

Mast height can be extended as the height of construction increases. As construction progresses, the extended mast can be guyed back to the structure, to limit the moments and forces imposed on the foundations.

### Tandem lifts

A tandem lift is a procedure whereby two cranes are used to lift one object (Fig. 2). It is used when a single crane would not have sufficient capacity to carry out the lift. Another common application is when an object is being lifted from horizontal to vertical, e.g. diaphragm wall reinforcement cages. Tandem lifts are more complex and require more planning than normal lifts.

### Crane foundations

Special software is used by crane suppliers to accurately calculate the outrigger loads and track bearing pressures.

Big cranes need big foundations. For example, a 750Te mobile crane lifting 50Te at 41.5m has an outrigger load of 140Te. A 1350Te crawler crane lifting 400Te at 48m has a maximum track pressure in excess of 500kN/m$^2$. Allowable ground bearing pressure for poor ground is less than 50kN/m$^2$ and engineered fill is around 200kN/m$^2$, so substantial temporary foundations may be required.

Consideration should be given to what parts of the permanent works will be affected by the crane foundations. This could be proximity to buried services, existing foundations or existing basements, or how the crane foundations will affect the new structure – integrating tower crane bases into building foundations, or on top of plunge columns, and tying tower crane masts into building cores (see Part 13[1]).

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**Figure 4**
**Derrick crane, Queensferry Crossing, Edinburgh**

PA

**Figure 5**
**Shear legs used to lift London Eye into position**

## Self-propelled modular transporters

SPMTs are road-going wheeled vehicles that can support very heavy loads (Figure 7). SPMTs were developed in the 1980s by the offshore industry to move very heavy loads through limited site access and place them to a vertical and horizontal accuracy of a few millimetres.

An SPMT module comprises four, six or eight axle lines of wheels, usually with four wheels to each line. A module is typically around 2.4m wide, although modules up to 3m wide are available. Axle lines are at around 1.5m centres, so a four-line module is 5–6m long and a six-line is 8–9m. The module height is around 1.2m. Modules can be connected together transversely and longitudinally.

Each wheel is driven by its own hydraulic motor and can rotate, allowing the SPMT to be steered in any direction. The wheels have independent hydraulically adjustable suspension of around 600mm. Power is provided by a modular power pack. SPMTs are controlled by a single operator. In operation, the fully laden module can travel at around 3mph.

Proprietary modular steel frames fitted on top of SPMTs can make up the height between the transporter and underside of the load. Hydraulic jacks and climbing assemblies can be fitted to provide further vertical adjustment.

Depending on manufacturer and configuration, each axle line has a capacity from 24Te to 44Te with ground bearing pressures from 7Te/m$^2$ to 12Te/m$^2$. Because of the plan dimensions of the transporter, the zone of influence can be quite deep.

Pros and cons of SPMTs are given in Table 2.

**When would you use an SPMT?**

Uses include bridge removal, installation or replacement during a (rail or road) possession, e.g. to build a new bridge off line outside possession and then, during a possession, remove the old bridge by SPMT and drop it onto a support, pick up the new bridge and drive it into position.

This technique has replaced the bridge slide techniques that were commonly used in the past (Figure 8)[3].

## Slides and launches

Slides and launches are still common methods of installing structures. To differentiate between a slide and a launch:

- a slide uses a slide track; temporary supports are aligned in the direction of travel and the structure is supported over the full distance of travel (Figure 9)
- a launch has a static leading temporary support position and the structure cantilevers over the top of it (Figure 10).

**Slides**

At its simplest, a slide requires a slide path, motive power and a means of steering. Typically, the slide path is made from a steel track fixed to support steelwork or a concrete foundation. The contact point between the load and slide track can be machinery moving skates or steel fabricated skid coated with a low-friction material.

Motive power can be a push from behind with a hydraulic jack mounted between the shoe and track, or a pull from a draw bar, wire strand or wire rope, powered by a hydraulic jack or mechanical winch mounted to the end of the slide track.

Table 3 presents pros and cons of slides.


**Figure 6**
**Mersey Gateway tower crane lifting 4Te at 80m radius over 120m high; approach viaduct moveable scaffold system in foreground, main span deck form traveller in background**

MERSEY GATEWAY CJV

**Figure 7**
**Self-propelled modular transporter, A6 Manchester Airport Relief Road: 45m span, 1300Te bridge deck, 350Te ballast, 300Te sills, 1950Te total. Very precise positioning allowed sill units to be stressed down onto anchors in pre-constructed foundations**

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**TABLE 2: PROS AND CONS OF SPMTs**

| Pros | Cons |
|---|---|
| Smaller footprint than crane | Can't cross obstacles, water |
| Not affected by high winds | Can't accommodate big changes in level |
| Low headroom means can transport underneath something | Can't tilt something from 0° to 90° |
| Bearing pressures low | Need good road surface – no soft spots |
| Do away with slide path temporary works | Ground deflections may affect buried services |
| Better at getting item into correct position | |
| May require a temporary road – but road cheaper than slide track | |

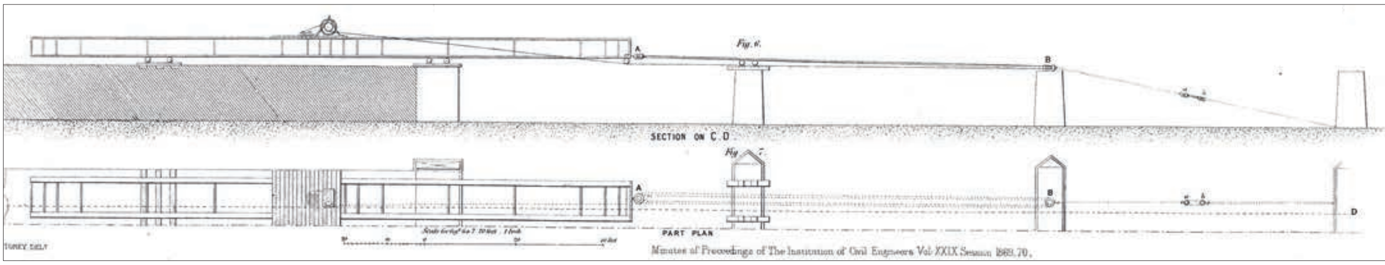


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Figure 8
**Launching of Pennair Bridge, India, 1868[3]: 510m railway viaduct, comprising 24 spans of 19.5m; speed of launch 128m in nine hours**

*When would you use a slide?*
Slides are used when size, space or lack of a suitable roadway mean that an SPMT is suitable.

### Launches

Launching requires the structure (usually a bridge) to have adequate strength and stability to cantilever into space over its last support. In the temporary condition, the structure must cope with the high reversed bending moments, high coexistent bending moments and shear forces, and remain balanced.

A launch requires a launching surface (rollers), motive power and guidance. The leading edge of the bridge can be pulled from an anchor point in front, on the landing side of the span, or the rear of the bridge can be pulled from the launch side. Winches or strand jacks can be used. Small structures, say up to 40m, can be pushed across by bulldozers.

Table 4 presents pros and cons of launches.

*When would you use a launch?*
Launches are still a popular way to build steel and concrete segmental bridges when the spans are larger than can be erected with a crane or an SPMT.

## Jacking

A jack is a device which applies or removes load from a structure. The simplest jack is a wedge driven into a gap. A more sophisticated version is two opposing wedges driven together. A screw jack acts as a tapered wedge wrapped around a cylinder. Screw jacks and folding wedge jacks are still commonly used, but for the heaviest loads hydraulic jacks are now used.

### Hydraulic jacks

A hydraulic circuit is a closed system containing fluid, usually oil, water or a water/glycol mix. Oil is used more commonly because it is inert and has low compressibility. For permanently filling flat jacks, resin can be used.

Figure 9
**Bridge slide on North Kent Line during rail possession: 110m span, 9500t (including abutments, piers, bridge deck ballast and track), 50 m slide, 40° skew**

VINCI CONSTRUCTION

*Types of hydraulic jacks*
A flat jack comprises two pressed steel discs welded around the perimeter. These are of low height, cheap and can be filled with resin to form permanent packs. Uses include preloading lintels supporting new openings in old buildings, preloading bearings under bridges and in underpinning.

Most jacks have an outer cylinder and inner piston. A flexible seal between the piston and cylinder stops the oil escaping. Some have bearing seals to provide transverse load transfer through the piston and into the cylinder. A jack that can be hydraulically powered when extending only is known as a single-acting jack. A double-acting jack can also be powered when retracting. These are used to accurately control the position of a piston, apply a pulling force or speedily retract a piston.

Jacks with a hole down the centre of the piston and cylinder are called hollow ram jacks; these are useful for pulling bars. Single and double-acting variants are available. The strand jack is a specially adapted variation of the hollow ram jack.

Hydraulic jacks can have a screw thread cut into the piston and a threaded collar. Once the lift is complete, the collar can be wound down on the jack so locking off the load.

Arrangements of packing used with the jacks enable the load to be raised more than the stroke of the jack (jacking and packing).

### Monitoring

It is important to monitor jack pressure and structure movement. Pressure gauges can be attached to individual jacks or banks of jacks connected by a common manifold. Movement can be monitored by surveying techniques, dial gauges with direct analogue readout, or electronically by a wide variety of transducers. It is also possible to monitor the change in strain of structural members during the operation. The jacking operation should be carried out sufficiently slowly that the monitoring system can be read and the data understood.

### Controlling the jacking operation

There are a number of methods to operate and control the jacks. These include:

- open circuit
- open circuit with steering jacks
- incremental operation
- synchronised pumps
- computer control.

The most appropriate method will depend on the structure and what needs to be achieved and it is best to seek expert advice.

### Hazards and pitfalls

Potential hazards include:

- overloading the structure
- overloading the jack, especially if placing load on top

**TABLE 3: PROS AND CONS OF SLIDES**

| Pros | Cons |
|---|---|
| Have smaller footprint than SPMTs | Expense |
| Can move bigger structures than SPMTs | If sliding down hill, a brake is required |
| Can be used when access isn't possible with SPMTs | Load can lurch or crab during pulling – modern proprietary jack-slide systems minimise this problem and operate well |
| Can be used when there is an obstruction that an SPMT can't cross (e.g. river) | |

**TABLE 4: PROS AND CONS OF LAUNCHES**

| Pros | Cons |
|---|---|
| Still popular way to build bridges | Piers need to be in place |
| Moment, deflection and reaction reduced by using lighter nose | Strength and stability of structure |
| | Not good for lattice structure, bottom chord has to take compression, local shear and local bending |
| | Big cantilever deflection |
| | Area on site required for counterbalance |

ALE & TRANSPORT FOR SCOTLAND

**Figure 10**
**Launching of Queensferry Crossing road bridge: 543m long viaduct, total weight of both girders 3150Te**

- running out of stroke when lifting or lowering – take elastic shortening, foundation settlement and deflection of the structure being jacked into account
- under-capacity when lifting; the structure will just not lift
- leaks – consider what could happen if there was a sudden release of oil (burst hose)
- blockages – make sure oil is entering and leaving all the jacks. When lifting, avoid one jack lagging behind; when lowering, avoid one jack sticking so that it attracts all the load.

## Other techniques

It is possible to build large structures *in situ*. The techniques being used to build the Mersey Gateway bridge in northwest England include travelling formwork systems (Fig. 6) that can launch themselves from pier to pier and allow an entire 70m span to be built at a time *in situ*.

It is also worth mentioning Ove Arup's concrete Kingsgate footbridge in Durham, which was built on dry land parallel to the river, then rotated into place.

## Legislation

Work described here will be covered by a number of sets of regulations; in the UK, these are primarily CDM 2015[4], LOLER[5] and PUWER[6].

## Conclusion

Lifting, moving and jacking is an immense subject. The challenge for the contractor is to come up with the best method – safe, most efficient, least disruptive, best use of programme – to construct the works.

At the end of the construction period, all the temporary works are removed and the structure is left complete and self-supporting. Once the temporary works are stripped away, little evidence is left of the methods used to support and build the structure. It's a bit like a conjuring trick, leaving future generations to ponder, 'How on earth did they manage to build that?'

This is one of the things I like about being a temporary works engineer.

**REFERENCES**

►1) McBride D. (2017) 'Temporary Works Toolkit. Part 13: The importance of understanding construction methodology', *The Structural Engineer*, 95 (7), pp. 32–36

►2) Grissell T. (1844) 'Account of the scaffolding used in erecting the "Nelson Column", Trafalgar Square', *Min. Proc. ICE*, 3, pp. 203–205

►3) Stoney E.W. (1870) 'Description of the Pennair Bridge, Madras Railway, N.W. Line', *Min. Proc. ICE*, 29, pp. 382–397

►4) *Construction (Design and Management) Regulations 2015*, SI 2015/51

►5) *Lifting Operations and Lifting Equipment Regulations 1998*, SI 1998/2307

►6) *Provision and Use of Work Equipment Regulations 1998*, SI 1998/2306

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## FURTHER READING

The following publications and websites provide further guidance on the techniques discussed in this article:

**CRANES**

►British Standards Institution (1998–2017) BS 7121 *Code of practice for safe use of cranes*, London: BSI

►British Standards Institution (2012–16) *BS EN 13001 Cranes*, London: BSI

►British Standards Institution (2007) *BS EN 1993-6:2007 Eurocode 3. Design of steel structures. Crane supporting structures,* London: BSI

►Skinner H., Watson T., Dunkley R. and Blackmore P. (2016) *CIRIA C654: Tower crane stability,* London: CIRIA

►Lloyd D. (ed.) (2003) *CIRIA C703D: Crane stability on site,* 2nd ed., London: CIRIA

►Construction Plant-hire Association (2014) *CPA 1402: Requirements for Tower Cranes Alongside Railways Controlled by Network Rail,* London: CPA

►Construction Plant-hire Association (2011) *TCIG 1101: The Climbing of Tower Cranes,* London: CPA

►Construction Plant-hire Association (2007) *TCIG 0701: Safe Use of Top Slew Tower Cranes,* London: CPA

►Construction Plant-hire Association (2010) *TCIG 0601: Safe Use of Self Erecting Tower Cranes,* London: CPA

**SPMTs**

►European Association of Abnormal Road Transport and Mobile Cranes (2016) *Best Practice Guide for Self-Propelled Modular Transporters* [Online] Available at: http://estaeurope.eu/media/downloads/ESTA_A4versie_DEFdigitalHR-pages.pdf (Accessed: July 2017)

►Oversize Baltic (2009) *Everything about self propelled modular trailers* (SPMT) [Online] Available at: www.transportoversize.eu/en/articles/id/4139/ (Accessed: July 2017)

►US Department of Transportation Federal Highway Administration (2017) *Self Propelled Modular Transporters (SPMTs)* [Online] Available at: www.fhwa.dot.gov/bridge/abc/spmts.cfm (Accessed: July 2017)

**SLIDES AND LAUNCHES**

►CIRIA (1977) R068: *Lateral movement of heavy loads,* London: CIRIA

►US Department of Transportation Federal Highway Administration website (2017) [Online] Available at: www.fhwa.dot.gov (Accessed: July 2017)

►Concrete Bridge Development Group (2005) *TP9: Fast construction – segmental and launched bridges*, Camberley: CBDG

►Concrete Bridge Development Group (2007) *CPS13: Incrementally launched concrete bridges, Camberley: CBDG*

►Concrete Bridge Development Group (2007) *CPS14: Jacked box underbridges using the Ropkins system,* Camberley: CBDG