BEBO Arch Systems

Installation Guide

BEBO Arch International AG

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Foreword

This instruction booklet outlines the construction procedures and specifications required to install *BEBO System* arch structures. It also covers the installation of precast spandrel walls and wing walls where used. It should be read in connection with the project design drawings and the BEBO System Technical Guide.

This document is relevant for all BEBO Series arches.

Prior to the commencement of a project, all supervisory personnel should carefully review these construction and installation instructions. A *BEBO* representative can be made available on request to be present at the construction site during installation. The responsibilities of this representative are to provide advice on the installation of the *BEBO System* and to act as an observer. If he observes any incorrect or unsafe practices, these will immediately be drawn to the attention of the site supervisor for his action. The BEBO representative, however, cannot assume liability for the construction procedure.

The information and data presented in this document is applicable for standard BEBO Arch System installations. The potential to use the *BEBO Arch System* must be evaluated on a project basis by a Consulting Engineer. Project specific data should also be provided to allow the engineer to determine the suitability, possible construction problems and other factors affecting the installation.

Statements in this guide are not to be construed as guarantees nor implied warranties.

In addition to the present instructions the *BEBO System Risk List* must be considered.

The instructions provided in this document are specific only for *BEBO System* applications. For non-BEBO specific details, tasks or situations, appropriate construction standards and procedures are to be followed.

Document Revisions

Modifications	Issued Visum/Date	Verified Visum/Date	Approved Visum/Date
2006 Release	Ni – Sep 06	W – Sep 06	W – Sep 06
Backfill Zone Revised	Ni – Jan 07	W – Jan 07	W – Jan 07
3rd Edition, 2009	SB – Aug 09	W - Sep 09	Ni - Sep 09

A. Fabrication, Handling and Transportation

1. FABRICATION

1.1 Applicable Design Standards

Fabrication of *BEBO System* elements must conform to the design drawings and the provisions of one of the following design codes (as specified on the drawings and in the structural design documentation of a specific project):

- AASHTO, Standard Specifications for Highway Bridges, 16th Edition, 1996;
- AASHTO, LRFD Bridge Design Specifications, 3rd Edition, 2003;
- British Standard, BS5400;
- Canadian CSI S6-00, Canadian Highway Bridge Design Code;
- Eurocode EC0 to EC7

On a project specific basis, other design codes (e.g. DIN, etc.) can be accounted for. Please contact BEBO Arch International AG for more information.

1.2 Concrete

As indicated in drawings.

1.3 Reinforcing Steel

As indicated in drawings.

No cold worked reinforcing steel of low ductility shall be used.

1.4 Minimum Concrete Cover over Reinforcement

As indicated in drawings.

1.5 Accuracy/Tolerances for Elements

All *BEBO System* elements must be accurate to within ± **6 mm** of their specified dimensions. Special care must be administered when casting bearing surfaces to ensure they will join correctly with other system elements.

2. HANDLING AND TRANSPORTATION

2.1 Cure Time

BEBO System elements **must not be lifted** from their casting beds **until** their strength is sufficient to prevent damage. The strength of the concrete must be great enough, so that, when lifted, the cast-in-place anchor pins are not pulled out from the concrete. The manufacturer of the **anchor pins** should be contacted to find the minimum concrete strength required, to be able to lift through the anchor pins and thus to lift the element.

2.2 Arch Elements

Care must be exercised in handling and moving *BEBO System* arch elements. BEBO arch elements are designed to be **cast, lifted, stored** and **hauled** in an **upright position** as shown in *Figure 1***.**

Careless or rough handling can not only be dangerous, but can also stress the element to a higher degree than would occur in the final structure. This mishandling can lead to the production of unnecessary cracking.

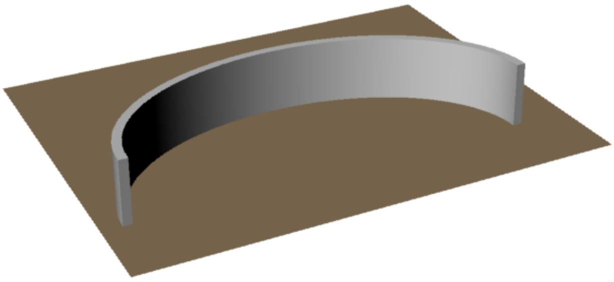


Figure 1: Casting, Lifting, Storage and Hauling Position of BEBO System Arch Elements

Arch elements are only to be lifted through the use of the anchors cast into the arch. The required locations of the anchors are specified in the drawings. Arch elements must not be lifted until the concrete has attained the specified strength.

Figure 2: Lifting of BEBO System Arch Element

Arch elements must be properly stored to prevent cracking, deformations, or other damage. It is recommended that timber supports are used, such as those shown in *Figure 3*. It is advised that timber supports encased in plastic are used for end elements. Timber supports in direct contact with concrete can tarnish the concrete and thus the curb face of the element. Unnecessary markings should be avoided on visible surfaces of the structure.

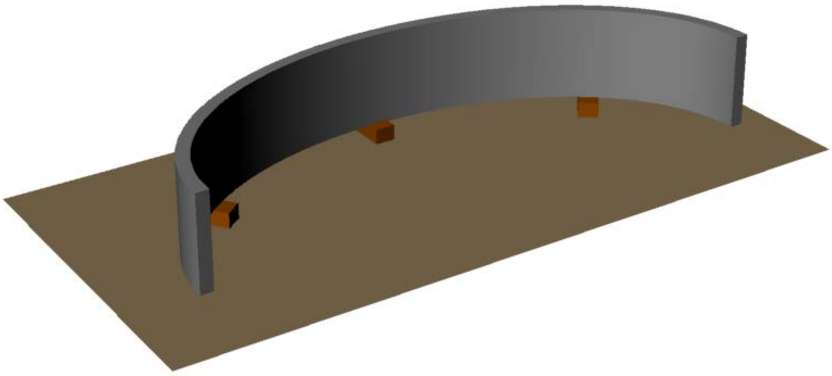


Figure 3: Storage of BEBO System Arch Element

Arch elements must not be **shipped** until the concrete has attained the specified compressive design strength (28 days).

Arch elements are shipped in the **upright** (as cast) position.

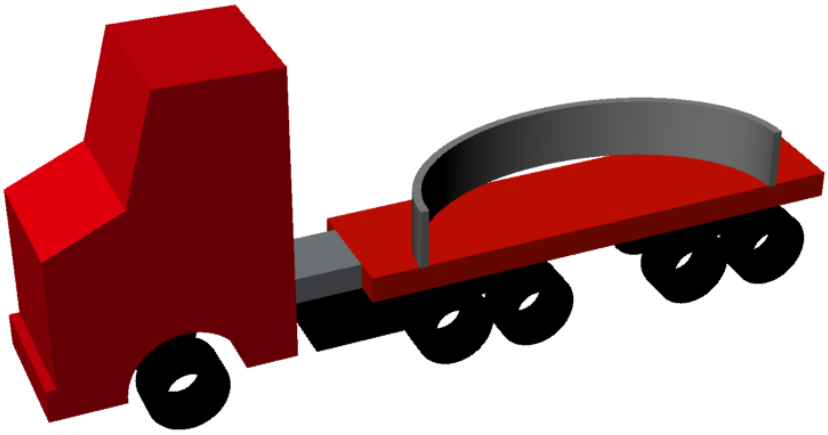


Figure 4: Transportation of Arch Element

NOTE: Ensure that the arch elements are correctly fixed during transportation. They should be sufficiently secured to be able to deal with sloping truck decks in the event of uneven road surfaces (site access roads).

2.3 Spandrel Wall Segments

Spandrel wall segments are **cast, stored** and **shipped** in the **flat position**.

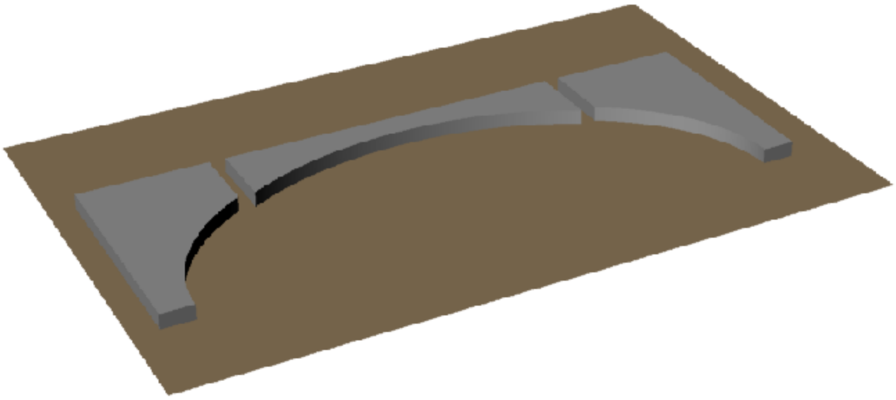


Figure 5: BEBO System Spandrel Wall Segments' Casting, Storage and Transportation Position

Spandrel Wall segments should **only** be lifted through the use of the cast-in anchors provided. The locations of the anchors are specified in the drawings.

Figure 6: Lifting BEBO System Spandrel Wall Segments

Store spandrel wall segments using timber supports as appropriate. Supports should be provided at the same locations as the cast-in-anchors in order to avoid loading/support conditions that differ from those assumed in the structural design.

Ensure that the side of the spandrel wall that will be visible in the final structure is facing upwards and is not in contact with the wooden supports. The wooden supports can leave unsightly marks on the element and it is desirable that these marks cannot be seen on the completed structure.

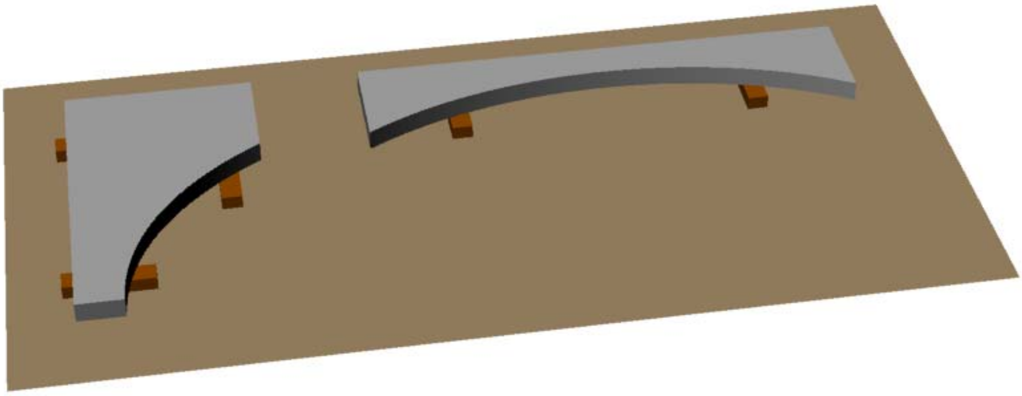


Figure 7: Storage of Spandrel Wall Segments

Spandrel wall segments must not be shipped until the concrete has attained the specified compressive design strength (28 days).

2.4 Wing Wall Elements

Wing wall elements are **cast, stored** and **shipped** as shown in *Figure 8*.

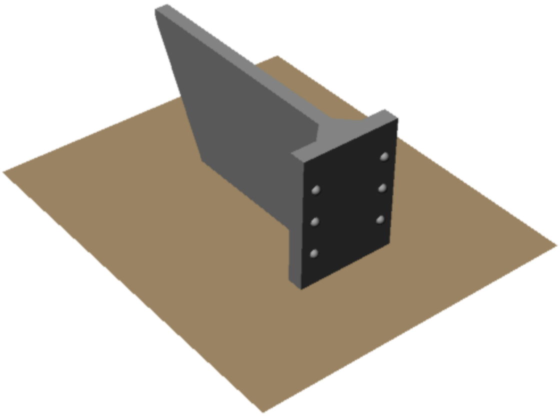


Figure 8: Casting, Storage and Shipping Position of Wing Wall Elements

Wing wall elements should **only** be lifted through the use of the cast-in anchors provided. The locations of the anchors are specified in the drawings.

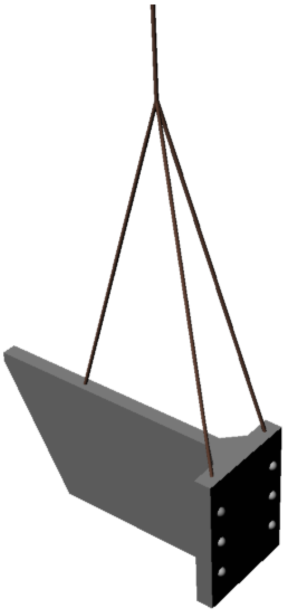


Figure 9: Lifting of a BEBO System Wing Wall Element

Store wing wall elements using timber supports as appropriate.

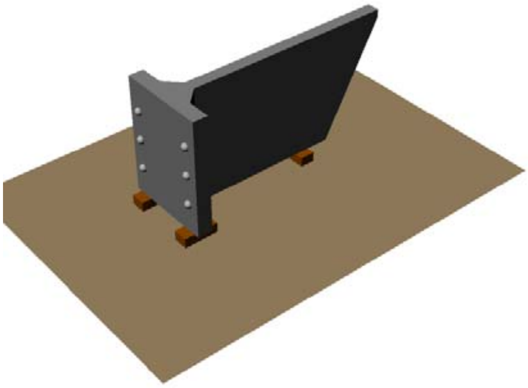


Figure 10: Storage of Wing Wall Element

Wing wall elements must not be **shipped** until their concrete has attained the specified compressive design strength (28 days).

2.5 MSE Walls and Other Systems

When non-BEBO spandrel and wingwalls are used that are compatible with the BEBO system, the product supplier must be contacted. The handling and transportation methods recommended by the product supplier must be used.

B. Construction

1. FOUNDATIONS

1.1 Foundation Design

Various types of foundations can be used for *BEBO System* structures. The type of foundation used depends on the circumstances encountered at each specific site. Most often, cast-in-place spread footings are used and are normally strip footings with a pedestal.

A generic footing design can be found in the *BEBO System Technical Guide*.

The foundations for arch elements, spandrel and wing walls must be **connected by reinforcement** to form **one full length monolithic body**. Expansion joints are not necessary (except under special conditions). Shrinkage and temperature cracks are acceptable and do not detract from the system's performance, durability and safety.

1.2 Critical Dimensions for Foundations

To ensure the correct installation of *BEBO System* elements, care and caution must be exercised in forming the support areas for the arch, spandrel and wing wall elements. Exercising special care will facilitate the rapid installation of the precast components.

It is important that the support area is constructed to the correct dimensions. These dimensions vary between arch type, size and subtype. It is important that the constructed dimensions correspond to the arch type being used.

The required dimensions are calculated differently for twin and single leaf arches. Please see the following sections for how to calculate the foundation dimensions for the required arch type.

The dimensions of the foundations/support areas should be **rechecked** BEFORE installation commences, along with the following criteria:

- The arch keyway is correctly aligned along the length of the foundation.
- The total length of the keyway should correspond to the sum of the widths of all arch elements, plus a 10 mm gap between each arch.
- The width of the keyway is correct for the arch type being used. See Appendix C for the keyway widths for each arch.

1.2.1 Critical Dimensions- Single Leaf

The distance X (as shown in *Figure 11*) is the distance between the backs of the two keyways. This distance allows for the span of the arch, plus sufficient space for the hardwood wedges and grouting.

X is defined as:

$$X = S_o + 200mm$$

Where:

- S_o = is the span of the arch measured to the outside of the arch
- X = distance from back of keyway to back of keyway

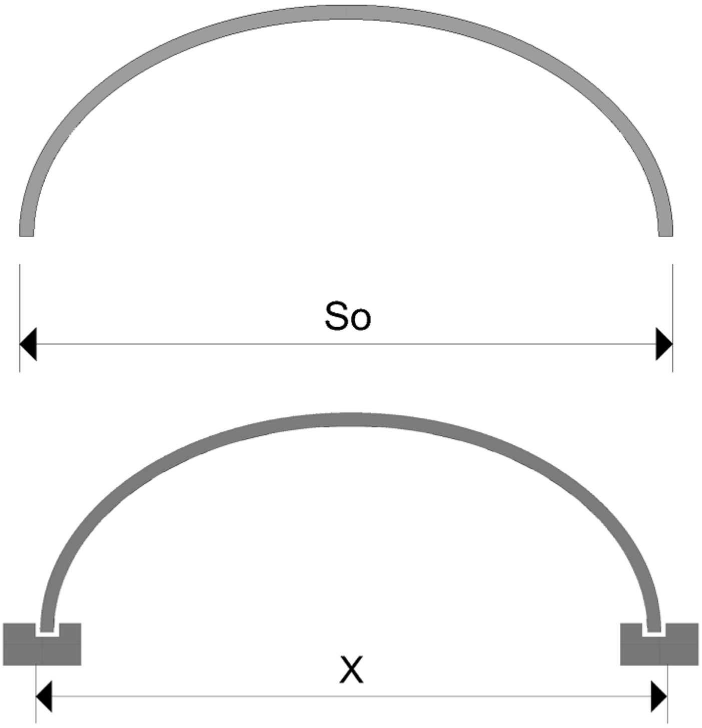


Figure 11: Critical Dimensions for Foundation Construction

See *Appendix A* for the dimension S_o and X for each arch size.

1.2.2 Critical Dimensions - Twin Leaf

Twin leaf arch structures experience deformation under self-weight upon installation.

For a proper installation of the arches this deformation must be compensated and the setting out span of the arches must be such that the actual crown level corresponds to the theoretical one.

X is defined as follows. Note that S_0 is replaced by $S_{deformed}$:

$$X = S_{deformed} + 200mm$$

See *Appendix A* for the dimension S_o and X for each arch size. Note that these are approximate values, because the deformations of reinforced concrete, naturally, experience considerable scatter.

2. LEVELLING PADS

2.1 Arch Element Levelling Pads

Levelling pads are required to guarantee the correct seating of the arch elements. Levelling pads can be either grout poured into the arch keyway or masonite shims. Material selection is at the contractor's discretion. Levelling pads must be approximately 50 mm thick, the width of the entire keyway and 600 mm long. This is to ensure that each arch element is resting on approximately 300 mm of pad at each joint (see *Figure 13*).

Figure 13: Arch Element Levelling Pads

The levelling pads are to be poured to **within 3 mm** of the required **elevation**.

The proportion, by loose volume, of cement to sand for the mortar mix must be 1 to 2.

No loads are allowed on the mortar levelling pads within 72 hours of their placement. Alternatively, fast setting cement can be used.

2.2 Spandrel Wall / Wing Wall Levelling Pads

Levelling pads are also required to guarantee the correct seating of the spandrel and wing walls. Incorrect seating leads to unsightly level differences of the bridge components.

Levelling pads must be approximately 50 mm thick and are to be poured to **within 3 mm** of the required **elevation**.

Levelling pads for wing walls must be constructed in a layout that allows each element to be supported at each corner as shown in *Figure 14*.

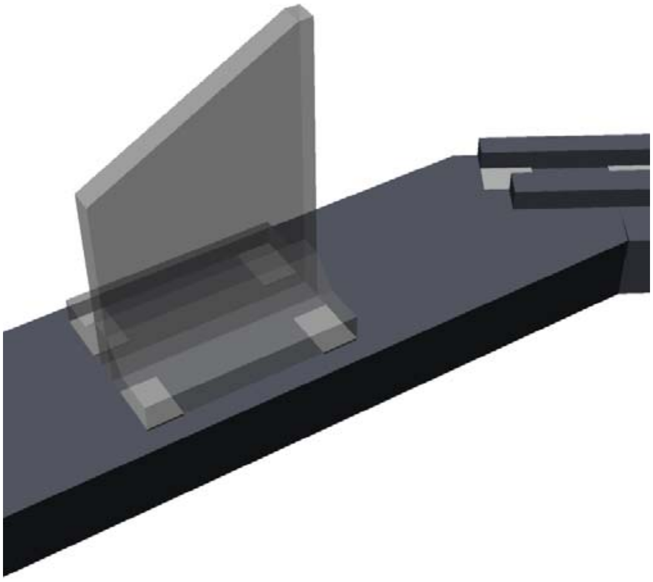


Figure 14: Wing Wall Levelling Pads

The proportion, by loose volume, of cement to sand for the mortar mix must be 1 to 2.

No loads are allowed on the mortar levelling pads within 72 hours of their placement. Alternatively, fast setting cement can be used.

3. SCOUR PROTECTION

Install scour protection to footings and bed of stream if required, according to the recommendations of the project's consulting engineer.

NOTE: Statistically, scour is the most frequent cause of bridge collapse worldwide.

4. DRAINAGE

The design of the standard system elements makes no specific allowance for hydrostatic pressure due to high ground water levels. When such conditions are present the structure should be adequately drained or the water pressure taken into account in the calculations.

Suggested drainage lines are shown in *Figure 15*.

In order to avoid the washing out of fines (piping) **all drainage lines (including weep holes) must be enclosed in or covered by appropriate filters** (geotextile and/or filter packages) as shown in *Figure 16*.

Note: Severe damage to the structure can occur if fines are washed out. Take special care where the structure is under frequent or constant water spill. Water mains behind the structure if broken can cause critical damage.

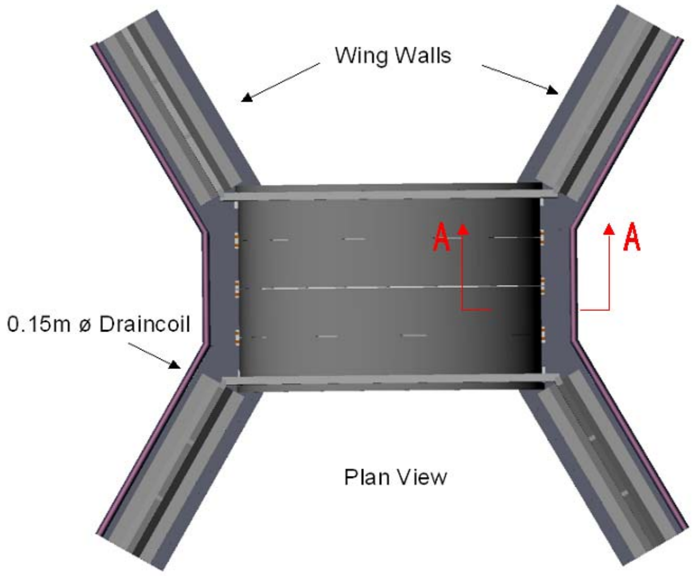


Figure 15: Drainage Line Locations

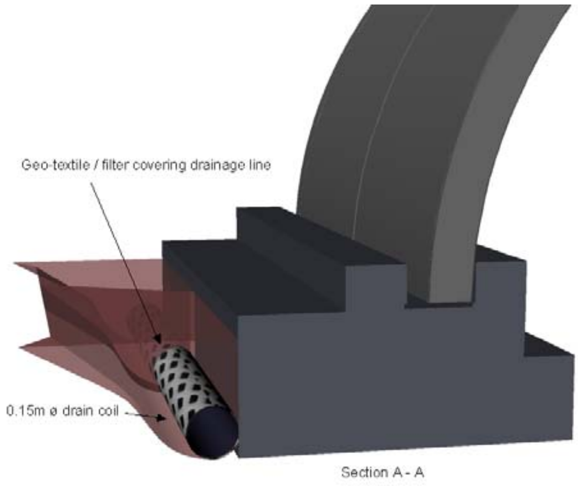


Figure 16: Drainage Lines- Cross-section

C. Installation Procedures for Precast Elements

1. GENERAL REQUIREMENTS

1.1 Cranes

The recommended method for installing the precast elements utilises one or two **double-drum cranes** with equal capacity on each drum.

If you are considering using an alternative method (to that which utilises a double-drum crane), please contact BEBO Arch International AG engineers to develop appropriate alternative installation procedures.

It is the responsibility of the contractor to ensure that cranes of correct lifting capacity are available to handle the precast elements. This can be accomplished by using the weights given for *BEBO System* components and by determining the lifting reach for each crane element. It is also the responsibility of the contractor to ensure that the cranes are correctly positioned on the ground. Site conditions must be checked well in advance of shipping to ensure proper crane location and to avoid any lifting restrictions.

It has been found through experience that trying to use a minimal crane size actually leads to inefficiencies and not to the desired efficiencies. As a general rule: a somewhat bigger crane gives a more efficient solution.

1.2 Rigging

Appropriate sized rigging cables and snatch blocks based on BEBO requirements should be available onsite. Cables of wrong lengths cause the arch to hang incorrectly and can cause not only problems on site, but can damage the element. The snatch blocks should be well lubricated to avoid corrosion or problems with sticking which can cause the arch not to hang plumb. Ropes should be on hand to control the arch during installation.

1.3 Tools

The following tools can be useful on site:

- Pinch point crow bars (2 per side)
- Sledge hammers (1 per side)
- Maul (to drive crown joints into place)
- Deep socket ratchets to tighten crown joint bolt (banana bolt)
- Chalk, tape measure and level (for setting out and checking)

1.4 Arch Positioning Aids

The following aids are recommended to assist with the positioning of the arch:

- A sufficient quantity of 40 x 190 x 400 mm concrete blocks should be available to allow their placement at two locations per arch leaf. These blocks are placed between the keyways back wall and the outside arch leg and are used to prevent lateral spreading of the arch after installation.
- Hardwood wedges to drive between the arch leg and the concrete blocks to adjust the position of the arch.
- 10 mm thick wooden boards, to be used to create the correct spacing between the elements as they are being positioned.
- 5 mm and 10 mm thick steel plate shims for various shimming purposes.

2. SITE PREPARATION

To ensure a smooth installation, a well prepared site is recommended.

2.1 Final Checks

The dimension of the keyway should be checked to ensure:

- That the keyways are parallel
- That the keyways are of the correct length. The length should be sufficient to accommodate all arch segments, plus a 10 mm spacing between each arch segment.
- The width of the keyway is correct for the arch type being used.
- The distance between the keyways is correct (As discussed in Section B 1.2 Page 7).

2.2 Setting Out

To ensure the correct positioning of the arch elements, it is recommended that lines of reference are drawn onto the keyways. These lines can then serve as a constant check of the orientation of the arches as the installation progresses.

One approach to setting out is to draw chalk lines **onto** the floors of the keyways. These lines are drawn at the desired final location of the outside-face of the arch.

NOTE: These lines also run over the levelling pads and are shown in *Figure 17.*

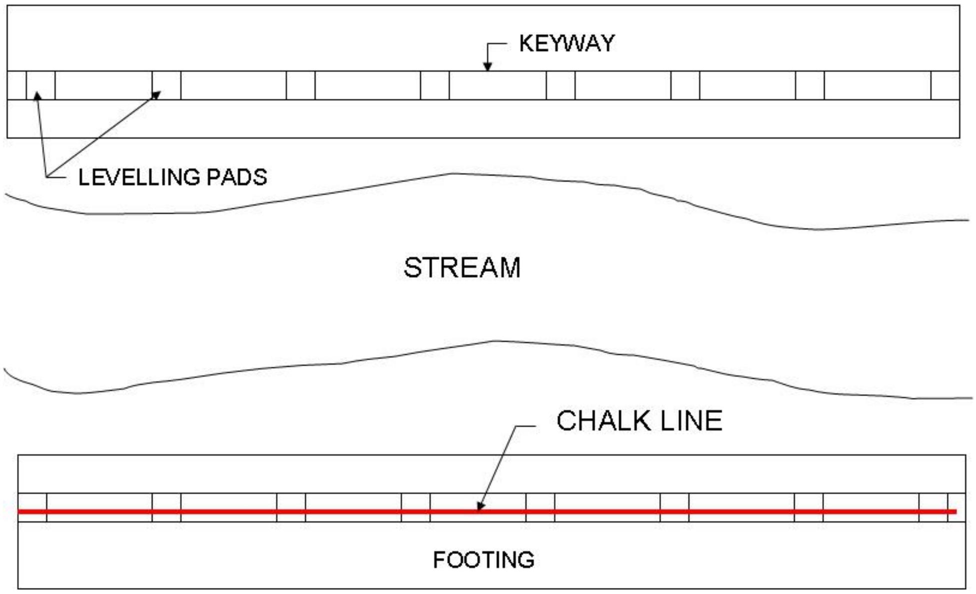


Figure 17: Setting-out Method 1 (Plan view)

While this method has been used extensively, it has been found by some contractors that under certain conditions it can be difficult to see the chalk line, when the arch segments are being lowered into place.

To overcome this problem, an alternative approach has been developed which continues to use a chalk line, but changes its location to improve visibility.

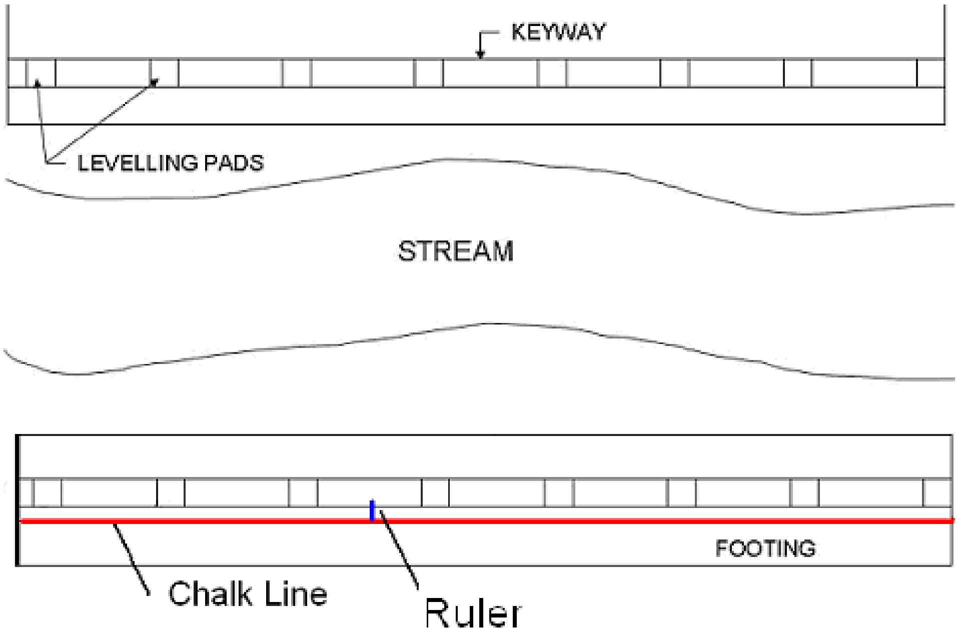


Figure 18: Setting-out Method 2 (Plan view)

In this method the chalk line is drawn on the outer curb of the footing (*Figure 18*), instead of inside the keyway, *Figure 18*. A ruler is then used to measure the required distance between the line and the outside of the arch leg. This method is shown in *Figure 19*.

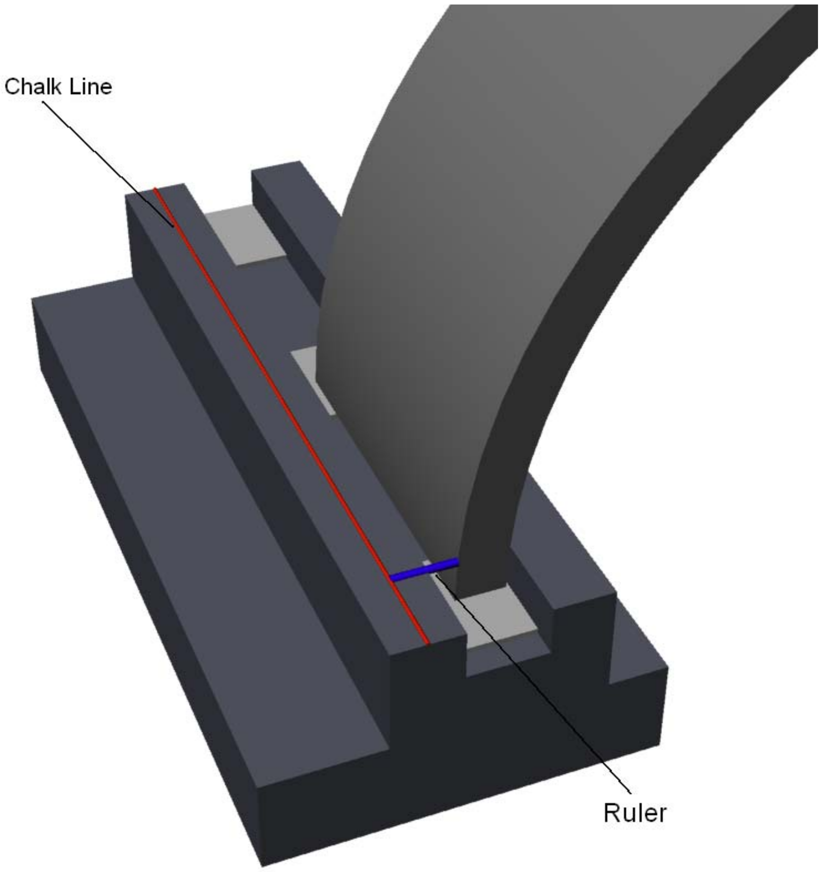


Figure 19: Setting-out Method 2

3. INSTALLATION OF ARCH ELEMENTS

Arch elements should be stored on the ground on site, only if appropriate protection measures are taken (see *Page 3*). Ideally they should be delivered to site, lifted from the truck and set directly on the foundations.

Figure 20: Unsafe Storage Position of Arch

Under **no circumstances** should the arch be stored as shown in *Figure 20.* If it is felt necessary to adopt such a position, contact BEBO Arch engineers for advice **<u>before</u>** such a position is adopted.

Spandrel wall segments and wing wall elements may be unloaded and placed on the ground on site until installed (see *Pages 5 and 6* for storage details).

The lift anchors provided in each element are the **only** means to be used to lift the precast elements. The elements must not be supported, stored or raised by other means than those given in the manuals and drawings.

Make sure that an “Arch End Element” (an arch element with curb) is placed as the first and last element (if used).

3.1 Single Leaf Arches

Single leaf arch elements are transported in the upright (as-cast) position as described in Section A 2.0 (*Page 2*). A crane is used to lift, rotate and place single-leaf arch elements in one exercise.

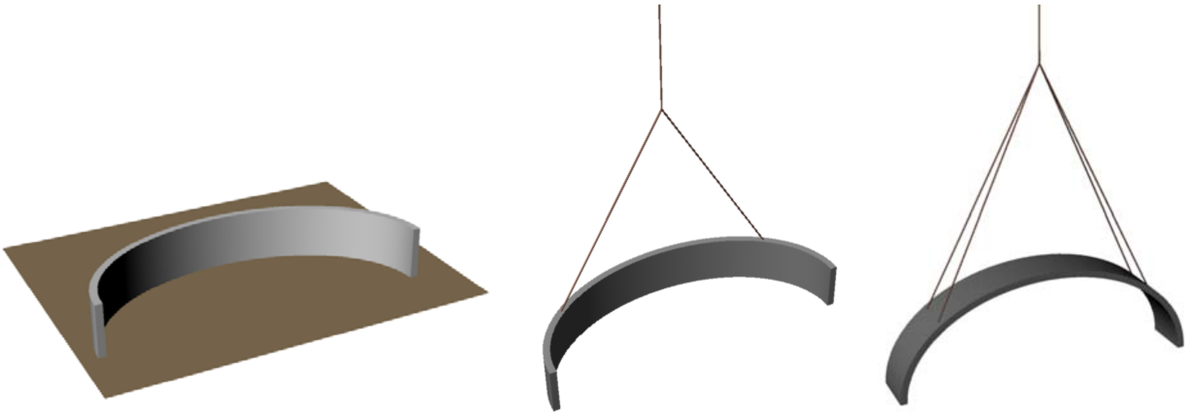


Figure 21: Handling and Rotation of the Arch

The arch element is then lowered into/onto the foundation key. **It is imperative that any lateral spreading of the arch element be avoided during and after installation.**

This is achieved by the use of the arch positioning equipment given in *Section B 1.4 Page 15*.

Figure 22: Measuring the Gap between Arches (left) and Hardwood Blocks and Wedges in Keyway

The concrete or hardwood blocks (shown in *Figure 22*) are placed between the keyway and the arch at a spacing of two blocks per arch leaf. These blocks can be rectangular or triangular in shape and can be made from either hardwood or concrete.

Hardwood wedges are then driven in between the arch leg and the concrete/hardwood blocks (*Figure 22*). Wedges are always triangular shaped.

Figure 23: Wooden Spacing Board Sits between Arches (View from above)

10 mm thick wooden boards are placed between the arch segments to create the correct spacing as shown in *Figure 23.*

For grouting procedure please see *Section 5.0 on Page 32*

NOTE: It is essential that these measures are in place before the release of the arch element from the crane.

Figure 24 shows a single leaf T-Series arch being installed (Next two pages).

Figure 24: Installation of Single Leaf Arches with a Double Drum Crane

Figure 24 (cont.): Installation of Single Leaf Arches with a Double Drum Crane

3.2 Twin Leaf Arches

Two double-drum cranes (or one double-drum crane and displaceable scaffolding) are required for the installation of the twin leaf precast arch elements.

Ideally, one crane shall be located on each (outer) side of the foundations to independently lift half-arch elements from the delivery trucks and into position. The two twin elements are lifted and positioned simultaneously.

Alternatively, if cranes are to be positioned on the same side of the foundations or within the arch span, they should be located so that the final jointing movement of the elements at the crown can be completed, without damaging the interlocking joint keys.

- Ensure elements are shipped in pairs, male to one side of the crossing and female to the other (based on the crown joint).

Twin-leaf arch elements are transported and lifted/rotated in a similar manner to single-leaf elements.

- To minimise crane movement, start installing arch elements at maximum crane reach and work towards the crane location.
- Ensure the arch elements are plumb once rotated.

Once the first end elements are installed, reverse the delivery of the remaining elements in order that the arch leaf edge anchors are facing out from the installed structure. When oriented this way, the edge lifting devices can be removed once the elements are in place. Otherwise the lifting devices must be removed before the arch leaves are lowered into position (*Figure 25*).

Figure 25: Arch being Lifted into Place with the Lifting Devices on the Outside of the Element

Figure 26 shows the installation procedure for twin leaf arches (Next two pages).

Figure 26: Double-drum Cranes Lifting, Turning and Installing a Pair of Twin Leaves

Figure 26(cont.): Double-drum Cranes Lifting, Turning and Installing a Pair of Twin Leaves

- Install the first arch leaf in its location with the crown 30 cm higher than the final resting location.
- Install the second arch leaf to the same elevation.
- Lower elements into place in unison.
- To prevent damage to the elements, the following steps must be followed closely. These steps must be carried out before releasing the tension from the cables. The following checks must be made:

1. The crown joint opening is correct (Vertical Section)

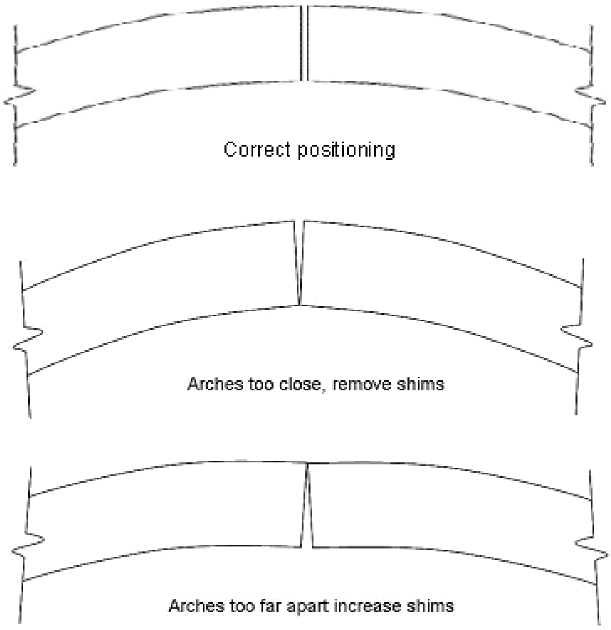


Figure 27: Correct Position of the Arches at the Crown Joint

2. The squareness of the arch elements is correct (left)

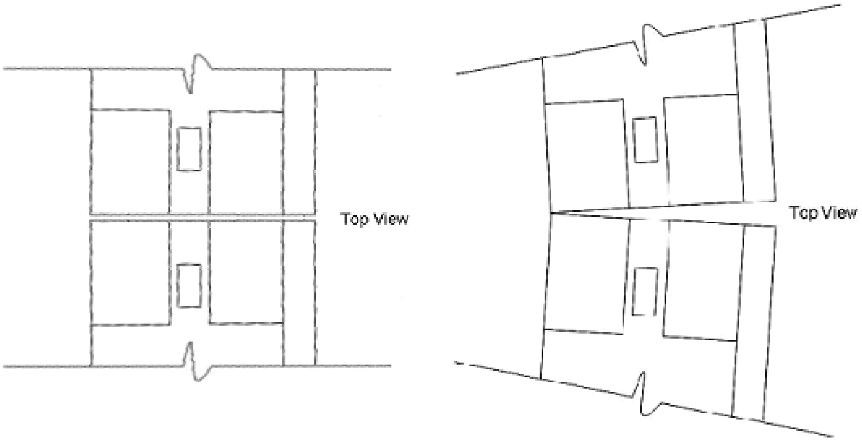


Figure 28: Correct and Incorrect Squareness of the Arch Elements

When the squareness is not correct (as shown in the diagram on the right in *Figure 28)* the following options are available to alleviate the problem:

a. Place steel shims between arch and keyway towards the edge where the joint is open.

b. Remove shims between arch and keyway towards the edge where the joint is tight.

c. Place steel shims under arch leg at location where the crown joint is open (this is usually required when there appears to be a "twist" in the installation).

Please note that the more time spent being accurate with the first elements leads to time savings while installing the remaining elements.

3. Before releasing the load of each arch half element from the crane, both elements must be blocked at the foundation key in the correct position (the same procedure as for single leaves, see Section B 3.1 Page 19).

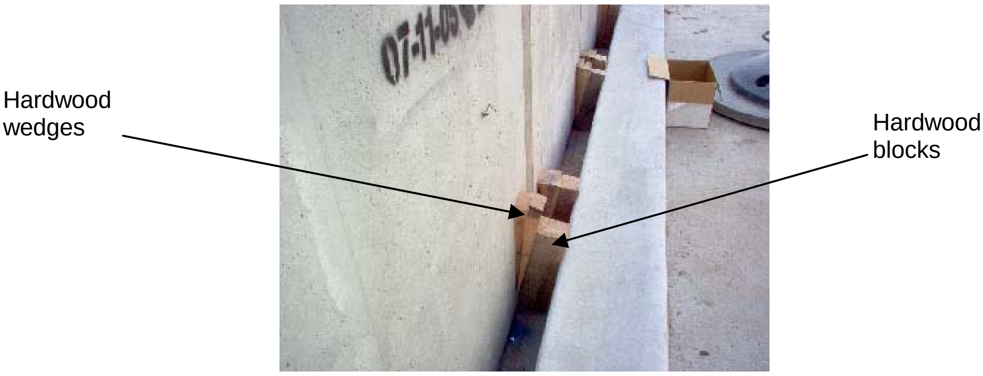


Figure 29: Hardwood Blocks and Wedges Between the Arch and the Keyway

4. Before the load is released, the curved tie rod ("banana bolt") must also be inserted and fixed in the block-outs at the crown joint.

Figure 30: Tie Rods (banana bolts) being inserted in the Crown Joint

Figure 31: Tie Rods (banana bolts)

After all the above procedures have been completed (1.,2.,3.,4.), the tension in the cables can finally be fully released.

The joints of the crown pockets must be waterproofed in preparation for the cast-in-place concrete. Reinforcement steel must then be inserted into the crown joint, before it is filled with cast-in-place concrete. This procedure should be carried out as shown in the drawings and in *Figures 32,33,34.*

***BEBO System* twin leaf profiles are designed for the arch's dead load to act on the three-pinned arch. In the case where scaffoldings are used for the installation, they must be removed (or lowered) <u>before</u> the crown joint is cast.**

Figure 32: Steel Reinforcement within Crown Joint (Pockets)

Figure 33: Filling the Crown-Joint with Concrete

Figure 34: Finished Crown Joint

The required compressive strengths for the cast-in-place crown joint concrete are listed in *Appendix B.*

4. INSTALLATION OF OTHER ELEMENTS

4.1 Installation of Wing Walls

A layer of mortar should be laid on to the foundation surface using the levelling pads for guidance. The wing wall elements can then be placed onto the levelling pads and **wet** mortar.

Once the wingwalls are correctly positioned they must be connected to the foundation. Pre cast holes are provided in the wing walls for this purpose.

A hole must be drilled into the foundation (through the precast holes in the wing wall footing). This hole must then be **cleaned before** it is filled with (typically) epoxy glue. A rod is then driven through the holes into the glue and then secured with a washer and a bolt.

4.2 Installation of Spandrel Walls

Place the spandrel wall segments onto the arch and foundations **on a wet layer of mortar**, starting with the centre piece. Add the adjoining lateral segments, attaching them temporarily to the arch end element and/or the wing walls.

NOTE: Spandrel wall segments may be placed on twin leaf arches only **after** the keyway has been grouted, the arch crown joint has been cast and the concrete has attained its specified strength.

The keyway joint between the spandrel wall and the first wing wall element should be clean, smooth and uniform so to provide an even bearing support for the spandrel wall.

4.3 Installation of MSE Spandrel Walls and Wing Walls

All MSE wall systems will be installed in accordance with the manufacturer's/supplier's specifications and requirements.

4.4 Installation of Bevelled Ends

The bevelled elements need to be attached to temporary works and propped or tied back to a firm stable binding. These props are normally required to stay in place for approximately two weeks after the elements have been stitched together.

Once the bevelled elements have been craned into place, the hardwood blocks and other positioning equipment should be used to ensure their correct seating of the element. Once all elements are correctly positioned, the temporary supports can be swung into position.

Final adjustments are then to be made to the temporary supports to level and align the elements. Once all temporary supports are in place, all elements should be checked for correct positioning and the required adjustments be made.

The bevelled ends solution is typically a more complicated solution, thus, when such a solution is chosen, detailed instructions and drawings are provided by BEBO Arch International AG.

Figure 35: Bevelled Ends with Temporary Supports

Figure 36: Temporary Supports for Bevelled Ends

5. GROUTING

All grout shall be 35 N/mm^2 (or as specified in the drawings) with a maximum aggregate of 6 mm and a maximum water/cement ratio of 0.40 in order to reduce shrinkage effects. The grout must be sufficiently flowable so that it completely fills all voids.

After the installation of all arch elements is complete, as per the instructions in Part C Section 3.0, the keyways must be grouted. The following procedure should be used:

- Fill the arch keyway with grout. Make sure that the space directly beneath the blocked-up arch legs is completely filled. Under no circumstances should the hardwood wedges be removed within the first 72 hours after grouting.
- After 72 hours the wedges should be removed and their holes filled in with grout.
- Grout the wing wall footing anchor rod holes.
- Fill the installation anchor recesses with grout.

Figure 37: The Arch Footing before Grouting and the Arch Footing Filled with Grout, before the Removal of the Hardwood Wedges

Figure 38: Grouting complete: Hardwood Blocks have been Removed and the Holes They Left behind have been Filled with Grout

6. WATERPROOFING

Various waterproofing measures can be used for a BEBO System structure. The waterproofing measures used are dependant on the specific requirements of each site.

As a minimum, the joints between the arch elements must be sealed by placing sections of 40 mm diameter preformed mastic in each joint. The joint is then covered with a 300 mm wide strip of a waterproofing membrane. To ensure that the strips remain in place during backfilling, the strips must be cemented to the precast elements with an adhesive compound. Joints between spandrel and wing walls are also to be covered with a waterproofing membrane.

A small strip of filter fabric is also cemented over the weep holes in the spandrel and wing wall elements (see drainage and required filters in Section B 5.0 Page 13).

Figure 39: Waterproofing of a BEBO Structure

Figure 39 shows the waterproofing of a BEBO structure in the USA.

D. Specifications for Backfilling

The backfilling operation creates one of the most important series of loads experienced by the structure.
The backfill is an integral, load carrying part of the structure. It must <u>permanently</u> fulfil its purpose.
Severe damage to the structure can result if proper procedures are not followed.

1. CRITICAL BACKFILLING ZONES

The critical zones for backfilling are as indicated in the figures below:

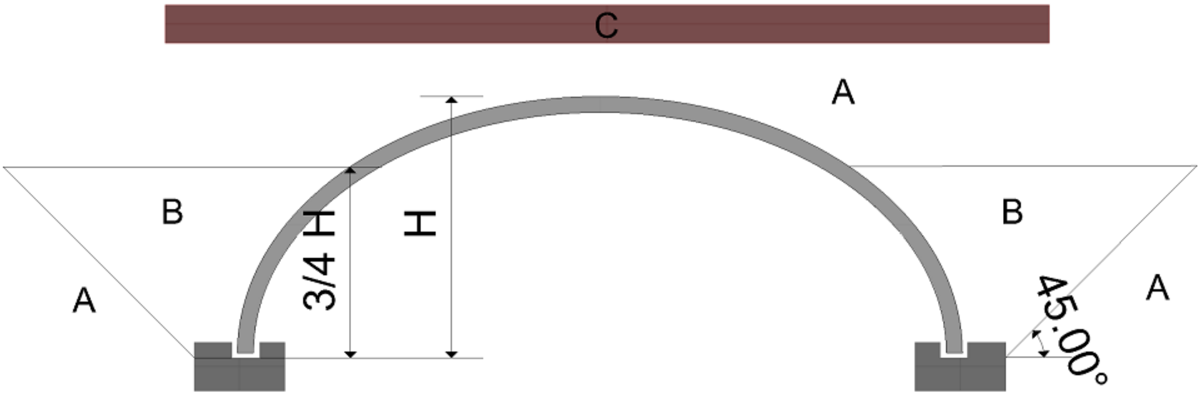


Figure 40: Citical Zones for Backfilling Alternative 1

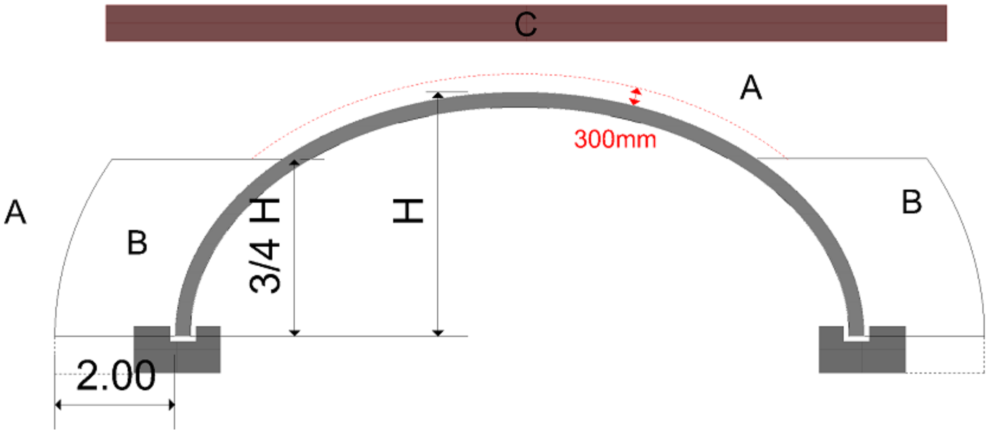


Figure 41: Critical Zones for Backfilling Alternative 2

Zone A:	Existing soil, well compacted embankment or overfill
Zone B:	Fill which is directly associated with bridge installation
Zone C:	Road structure

2. REQUIRED BACKFILL PROPERTIES

2.1 Zone A

Zone A requires natural ground or fill material with properties, filling procedures and **compacting** procedures, equal to that of normal road embankments.

Natural ground is to be **stable** enough to effectively support the arch elements. As a guide, the existing natural ground should exhibit properties (especially density) which are similar to those of Zone B material. This should be true of the material which lies within a minimum lateral dimension of one arch span outside of the arch footing.

2.2 Zone B

Generally, soils that meet the following **basic requirements** are acceptable:

$\phi' \geq 30^0$	(angle of internal friction, in compacted state)
$w_L \leq 40\%$	(liquid limit)
$I_p \leq 10\%$	(plasticity index)

Soils shall be reasonably free of organic matter, and, close to concrete surfaces, free of stones larger than 75 mm in diameter.

Materials with gradations that fall within the following limits (shaded area of *Figure 42*), **normally** fulfil the above basic requirements:

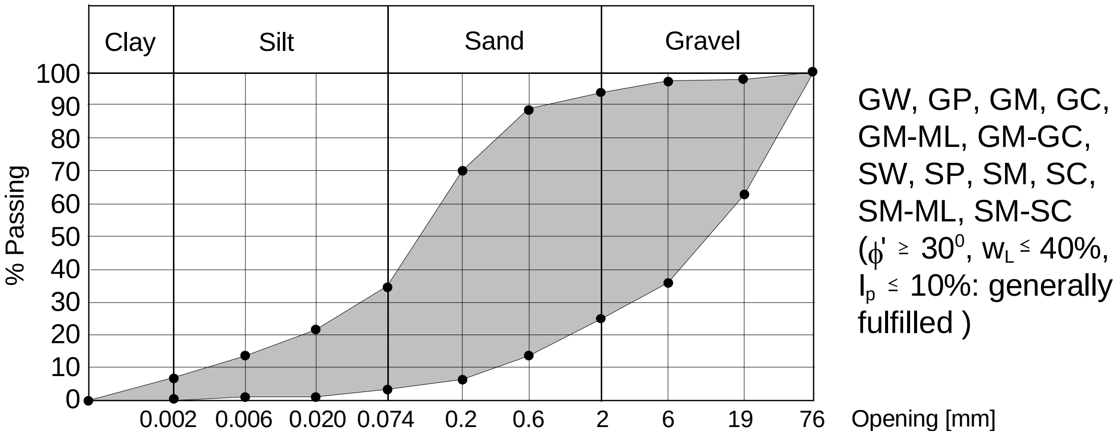


Figure 42: Zone B Gradation Limits

Soils should have a **water content** that allows the required compaction to be obtained. This is especially critical for soils of the USCS groups **SM-ML and SM-SC**.

In order to avoid **collapse settlement**, soils should have a **water content** at the Proctor Optimum or slightly on the **wet side**. Avoid compacting soils on the dry side of the Proctor Optimum moisture content, since this can lead to collapse settlement when the water content increases.

The following USCS soil groups are **not acceptable** as backfill material in their natural state:

GC-CH	(gravel with high plasticity clay)
SC-CH	(sand with high plasticity clay)
CL	(gravelly and/or sandy, clayey silt)
OL	(gravelly and/or sandy, organic silt)
CH	(gravelly and/or sandy, silty clay)
OH	(gravelly and/or sandy organic silty clay)
MH	(gravelly and/or sandy high plasticity silt)

It is however possible to improve the strength of the majority of the soil types above by adding cement or lime and thus creating "soil cement". This material can then be used for backfilling.

The soils **OL AND OH** however are exceptions in the above soil types**.** These soils should not be used as backfill material, even when mixed to create soil cement.

The suitability of backfill material can also be determined using AASHTO Designation M 145-87. In general, soils groups A-1, A-2, A-3 and A-4 are acceptable (see *Table 2* below, Bureau of Public Roads Classification).

Table 2: Acceptable and Non-acceptable Soils for AASHTO M 145-87

TYPICAL USCS MATERIALS	Group	Sub-Group	Per Cent Passing U.S. Sieve No.			Character of Fraction Passing No. 40 Sieve		Group Index No. [1]	Soil Description
			10 [2mm]	40 [0.4mm]	200 [0.074mm]	Liquid Limit	Plasticity Index		
GW, GP, SP	A-1			50 max.	25 max.		6 max.	0	Well-graded gravel or sand; may include fines
GM, SW, SP, SM		A-1-a	50 max.	30 max.	15 max.		6 max.	0	Largely gravel but can include sand and fines
		A-1-b		50 max.	25 max.		6 max.	0	Gravelly sand or graded sand; may include fines
GM, SM, ML, SP, GP	A-2				35 max.			0 to 4	Sands and gravels with excessive fines
SC, GC, GM		A-2-4			35 max.	40 max.	10 max.	0	Sands, gravels with low-plasticity silt fines
		A-2-5			35 max.	41 min.	10 max.	0	Sands, gravels with plastic silt fines
SC, GC		A-2-6			35 max.	40 max.	11 min.	4 max.	Sands, gravels with clay fines
SC, GC		A-2-7			35 max.	41 min.	11 min.	4 max.	Sands, gravels with highly plastic clay fines
SP,SM,SW	A-3			51 min.	10 max.		Nonplastic	0	Fine sands
ML, SM, SC	A-4				36 min.	40 max.	10 max.	0 max.	Low-compressibility silts
MH, OH, ML, OL	A-5				36 min.	41 min.	10 max.	12 max.	High-compressibility silts
CL, ML, OL	A-6				36 min.	40 max.	11 min.	16 max.	Low-to-medium-compressibility clays
	A-7				36 min.	41 min.	11 min.	20 max.	High-compressibility clays
OL, CH, MH, OH, CL, ML		A-7-5			36 min.	41 min.	11 min.	20 max.	High-compressibility silty clays
OH, CH, MH, CL, ML, OL		A-7-6			36 min.	41 min.	11 min.	20 max.	High compressibility, high-volume-change clays
PT, OH	A-8								Peat, highly organic soils

☐	Acceptable Soils	▨	Non-acceptable Soils

[1] Determination of Group Index No. see formulae below:

Group Index GI = (F - 35) · [0.2 + 0.005 · (LL - 40)] + 0.01 · (F - 15) · (PI - 10), in which:

F = Percentage passing No. 200 (0.074 mm) sieve, expressed as a whole number. This percentage is based only on the material passing the 3-in (75 mm) sieve.

LL = liquid limit

PI = plasticity index

Index No. 0 - 4 indicates a "good" material
Index No. 5 - 14 indicates a "fair" material
Index No. 15 - 19 indicates a "poor" material
Index No. 20 or greater indicates a "very poor" material

The necessary fill properties for Zone B can also be achieved by the use of **Controlled Low-Strength Materials** (CLSM; flowable or self-compacting fill). This can be particularly beneficial in restricted conditions (narrow excavations) where compacting is difficult and/or when placement of backfill is time-consuming (multiple-span structures). **Compressive strengths** of 0.7 N/mm^2 or less are appropriate for CLSM. Contact BEBO in specific cases.

2.3 Zone C

Zone C is the road section and consists of gravel, asphalt or concrete built in compliance with local engineering practices. The s**tandard minimum overfill height is 0.45 m over the crown of the arch (including the pavement)**. There should be at least 100 mm of select fill between the arch extrados and the bottom of the pavement. Shallower overfill heights are possible under certain conditions. Contact BEBO Arch International AG for more information.

All standard designs use a specific weight of 20kN/m^3 for Zone B and C material. Differing specific weights (lightweight fill, iron ore, etc.) need to be analysed separately and checked by BEBO Arch International AG.

3. PLACING AND COMPACTING FILL

3.1 General Requirements and Procedures

Backfilling operations at the sides of the arch shall not commence before the keyway grout has attained **half** of the required final compressive strength, i.e.**17.5 N/mm^2**.

For twin-leaf arches, the cast-in-place crown joint concrete must attain the full required compressive strength (see *Appendix B*), prior to starting the backfilling operation.

The dumping of backfill is not permitted within 1m of the structure. See F*igure 43* for the extent of this 1m boundary.

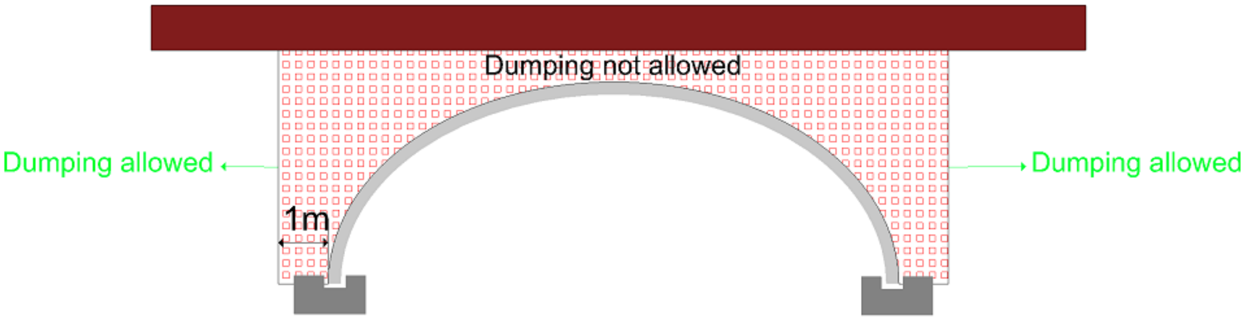


Figure 43: Restrictions on Dumping of Fill Material

The fill must be placed and compacted in layers not exceeding 0.5 m in their compacted state. The maximum difference in the surface levels of the fill on opposite sides of the arch must not exceed 1.0 m. Marks are painted and numbered on arch elements to indicate each backfill level. This serves as a guide for equipment operators and helps to ensure that the maximum difference is not exceeded. In special cases, ask BEBO whether higher differences can be used.

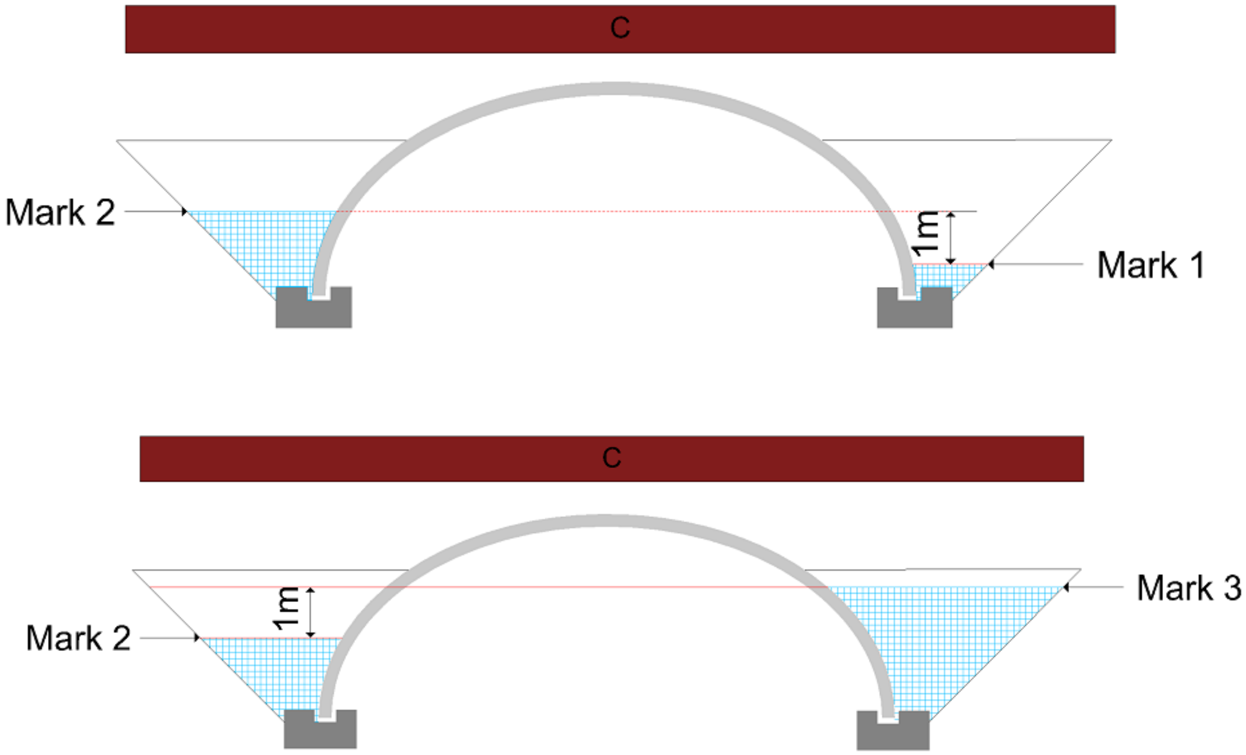


Figure 44: Guidance for Backfill Steps

The fill behind the **wing walls** must be placed at the same time as that of the arch fill and be placed in horizontal layers not exceeding 0.5 m per layer.

The backfill of **Zone B** must be **compacted** to a minimum **of 98% of the maximum dry density determined by the Proctor Standard test.**

To avoid damage, fill located directly adjacent to the arch and spandrel walls as indicated in *Figures 45 and 46* should be compacted using hand-operated equipment.

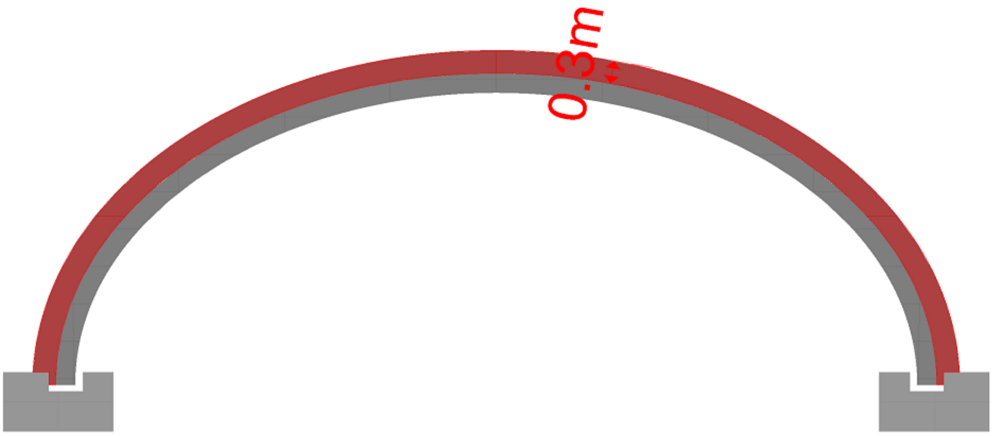


Figure 45: Red Zone- Use Hand Operated Compaction Equipment Only

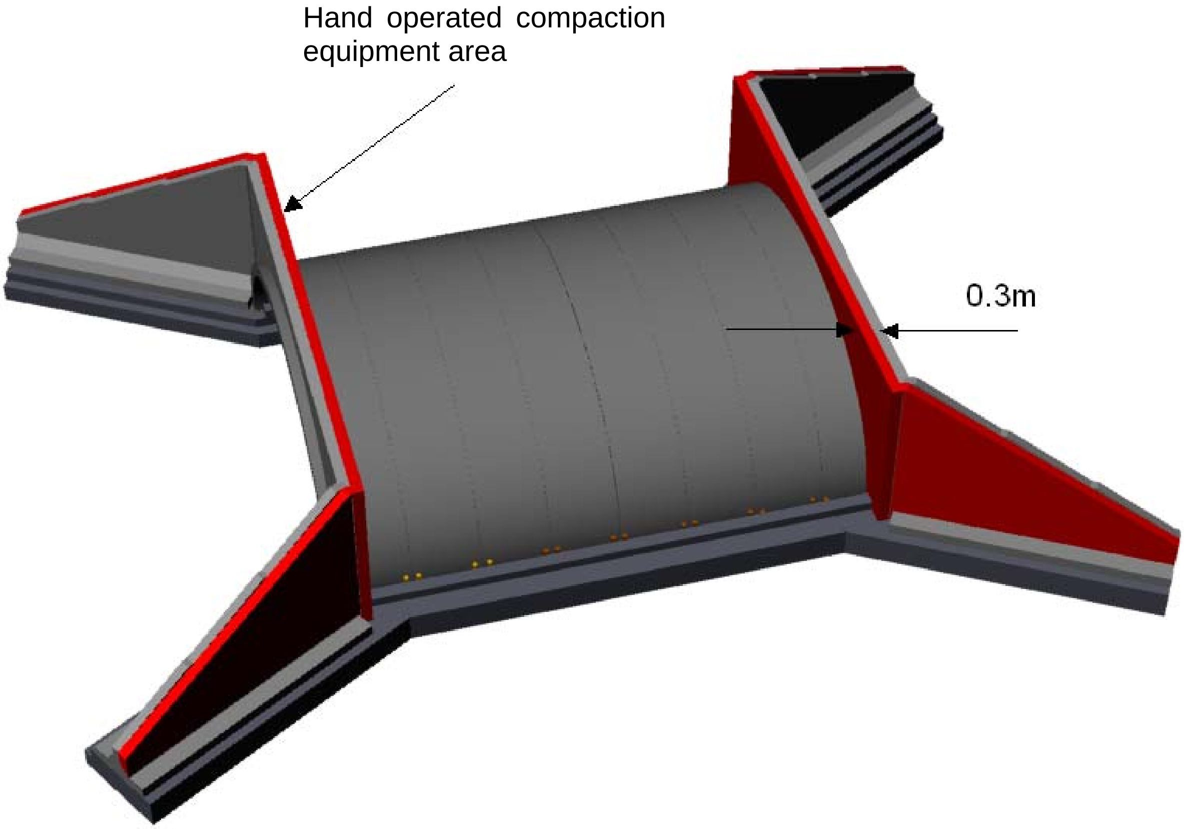


Figure 46: Red Zone - Use Hand Operated Compaction Equipment Only

Heavy vibrating compaction equipment should be started and switched off outside the limits for dumping as shown in *Figure 43.* The vibration frequency should be at least 30 revolutions per second.

Figure 47: Compaction with a "Jumping Jack"

Figure 48: Hand-operated and Heavy Compaction Equipment

The backfill behind the wingwalls (outside of Zone B) requires no special material or compaction methods. This backfill should still however satisfy the requirements for normal embankments.

3.2 Weight Restrictions for Construction Machinery

In the immediate vicinity of the arch, there are restrictions for the use of heavy construction machinery during the backfilling operation.

The bare arch may not be crossed by **any** construction equipment.

The shaded area in *Figure 49* is restricted to construction equipment with a maximum weight of **10 tonnes**.

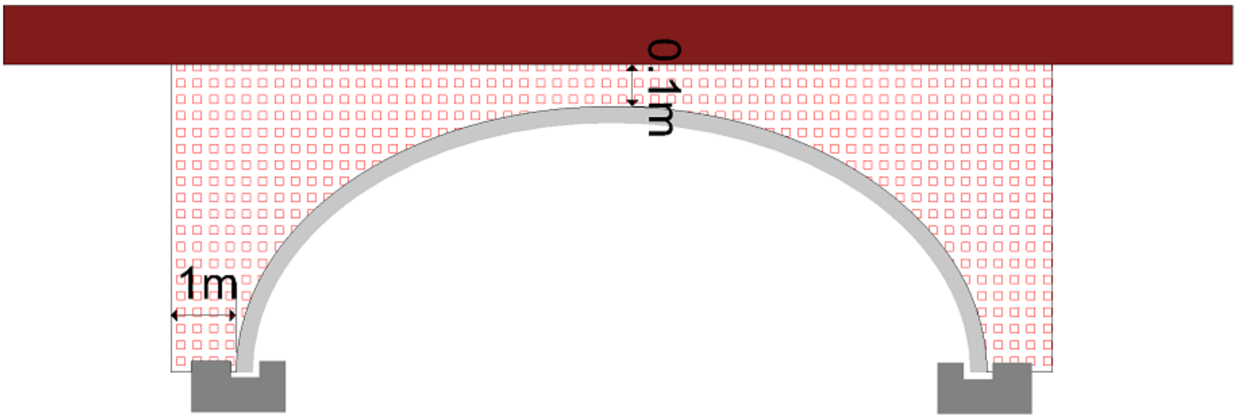


Figure 49: Weight Restriction Area

After the compacted fill level has reached a minimum of 0.3m over the crown of the arch, construction equipment with a maximum weight of **30 tonnes** may cross the arch.

After the compacted fill level has reached 0.5 m over the crown of the arch, construction equipment within the design load limits for the road may cross the arch.

Especially heavy equipment may cross the arch at greater depths of overfill. For the minimum depths of overfill required for specific extra heavy equipment, please consult BEBO Arch International AG engineers.

E. Inspections

1. SETTLEMENTS AND HORIZONTAL DISPLACEMENTS

Settlement and horizontal displacement of the foundations should be monitored to ensure that they are within the allowable design limits. The allowable values are given in the table in *Figure 50*. These values should give an indication of the acceptable settlements and deformations along the length of the foundations. In certain cases the allowable displacements will be given in the design documents of the specific BEBO structure.

In general, the first measurement should take place after the installation of the *BEBO System* elements, a second after completion of the backfilling and a third before the opening of the bridge to traffic. Further measurements can be required according to local conditions.

	Δ h (total span change)	Δ v (between opposite footings)
Displacement	1/1000 of arch span	1/200 of arch span

Figure 50: Allowable Displacements for Foundations

The maximum difference in vertical displacements ’v’ should not exceed 15 mm per 10 m along the length of one foundation.

In conjunction with possible horizontal displacements of the foundations, check for visible cracks in the concrete of the arch intrados. Fine or hairline cracks of up to 0.2 mm are to be expected in the crown area and are not harmful.

NOTE: The above values are very general and are often very conservative. Where large settlements are expected, contact BEBO Arch International for project specific advice.

NOTE: There may be other (local) factors present which may require smaller allowable settlements/displacements. Such factors include nearby structures, service lines in the backfill (especially water and gas mains) or especially narrow tolerances at the top surface.

F. T-Series

The construction and installation of the T- Series is similar to that of the E and C Series. There are, however, some key differences which need to be addressed and are discussed below. The differences and appropriate actions are described and where useful, the page number of the corresponding information for the E and C Series is given in brackets.

- The foundations should be constructed as required by the project drawings.
- The T-Series arch sits in a keyway which is constructed on to the foundation block. The main difference of the T-Series keyway, is that it has only an outer curb, unlike that of the E and C Series which usually has an outer and an inner curb. The distance between the two outer curbs is known as X (Pages 8 and 9) and is found for the T Series arches using the formula below:

$$X = S_o + 200mm$$

Where:

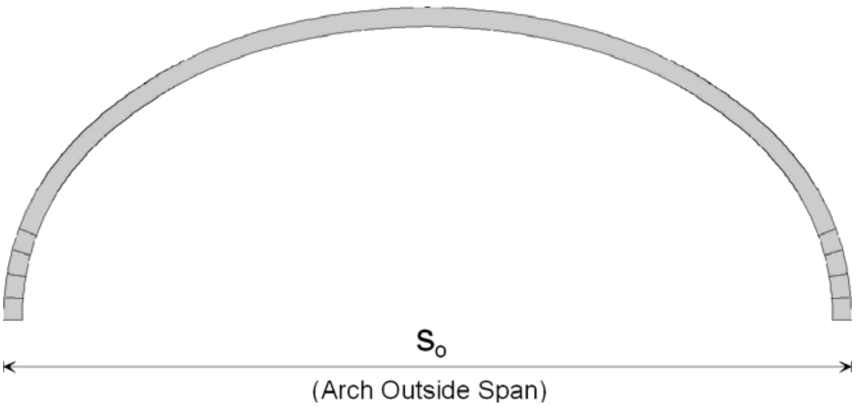
- So = is the span of the arch measured to the outside of the arch (Given in project drawings)
- X = distance from back of keyway to back of keyway

This formula is applicable for both single and twin leaf T-Series arches.

- When a single leaf arch element is being installed, the actual span of the arch should be checked BEFORE the tension is released from the crane cables. This should be checked to ensure that there is NO SPREADING of the arch.
- It is particularly important to check the crown level of twin leaf T-Series' arches. The height of the crown should be measured by a surveyor while the crane cables are still under tension.
- Under no circumstances should the crown level be below that of the specified level given in the drawings. A crown level which is up to 100 mm higher than the design level is acceptable. If the measured crown level is not within the specified limits, it must be adjusted using the "arch positioning equipment" BEFORE the tension is released from the crane cables.
- The backfill applied to the T-Series arches does not significantly contribute to the carrying capacity of the arch, as it does with the C and E Series arches. As a result, there is no requirement for Type B backfill. All backfill over the arches is of Type A (See Page 35 for diagrams and Page 36 for further information) and thus needs to satisfy the requirements for normal road embankments.

Appendix A

Arch Outside Spans: E12 - E48



E12	s_o [mm]	X [mm]
E12/0	3782	3982
E12/1	3994	4194
E12/2	4064	4264
E12/3	4064	4264

E16	s_o [m]	X [mm]
E16/0	4734	4934
E16/1	5046	5246
E16/2	5224	5424
E16/3	5282	5482
E16/4	5282	5482

E20	s_o [m]	X [mm]
E20/0	6036	6236
E20/1	6298	6498
E20/2	6450	6650
E20/3	6502	6702
E20/4	6502	6702

E24	s_o [m]	X [mm]
E24/0	7314	7514
E24/1	7544	7744
E24/2	7676	7876
E24/3	7722	7922
E24/4	7722	7922
E24/5	7722	7922

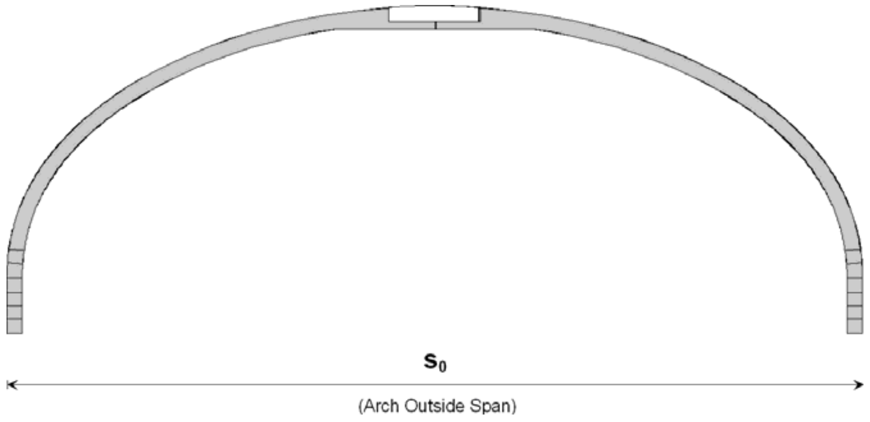
E30	s_o [mm]	X [mm]
E30/0	9308	9508
E30/1	9502	9702
E30/2	9614	9814
E30/3	9652	9852
E30/4	9652	9852
E30/5	9652	9852

E36	s_o [m]	X [mm]
E36/0	11048	11248
E36/1	11270	11470
E36/2	11412	11612
E36/3	11476	11676
E36/4	11480	11680

E42	s_o [m]	X [mm]
E42/0	12878	13078
E42/1	13098	13298
E42/2	13242	13442
E42/3	13306	13506

E48	s_o [m]	X [mm]
E48/0	14964	15164
E48/1	15112	15312

Arch Outside Spans: E54T - E84T; E15.5mT



E54T	**s_o [mm]**	**0s [mm]**	**$S_{deformed}$ [mm]**	**X [mm]**
E54T/0	16936	10	16926	17126
E54T/1	17034	15	17019	17219
E54T/2	17070	20	17050	17250
E54T/3	17070	25	17046	17246
E54T/4	17070	29	17041	17241
E54T/5	17070	34	17036	17236
E54T/6	17070	39	17031	17231

E60T	**s_o [mm]**	**0s [mm]**	**$S_{deformed}$ [mm]**	**X [mm]**
E60T/0	18968	16	18952	19152
E60T/1	18999	21	18978	19178
E60T/2	18999	26	18973	19173
E60T/3	18999	31	18968	19168
E60T/4	18999	36	18963	19163
E60T/5	18999	41	18958	19158

E66T	**s_o [mm]**	**0s [mm]**	**$S_{deformed}$ [mm]**	**X [mm]**
E66T/0	20802	23	20779	20979
E66T/1	20828	30	20798	20998
E66T/2	20828	37	20791	20991
E66T/3	20828	43	20785	20985
E66T/4	20828	50	20778	20978
E66T/5	20828	57	20771	20971

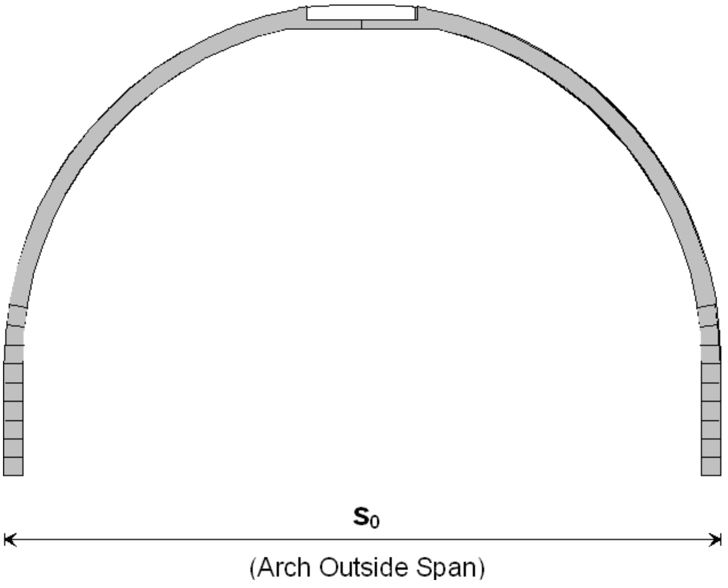
E72T	**s_o [mm]**	**0s [mm]**	**$S_{deformed}$ [mm]**	**X [mm]**
E72T/0	22662	22	22640	22840
E72T/1	22734	28	22706	22906
E72T/2	22760	35	22725	22925
E72T/3	22760	41	22719	22919
E72T/4	22760	47	22713	22913
E72T/5	22760	54	22706	22906
E72T/6	22760	60	22700	22900

E78T	**s_o [mm]**	**0s [mm]**	**$S_{deformed}$ [mm]**	**X [mm]**
E78T/0	24502	25	24477	24677
E78T/1	24566	34	24532	24732
E78T/2	24588	43	24545	24745
E78T/3	24588	52	24536	24736
E78T/4	24588	61	24527	24727
E78T/5	24588	70	24518	24718
E78T/6	24588	79	24509	24709

E84T	**s_o [mm]**	**0s [mm]**	**$S_{deformed}$ [mm]**	**X [mm]**
E84T/0	26338	28	26310	26510
E84T/1	26438	36	26402	26602
E84T/2	26496	43	26453	26653
E84T/3	26518	51	26467	26667
E84T/4	26518	58	26460	26660
E84T/5	26518	66	26452	26652
E84T/6	26518	73	26445	26645
E84T/7	26518	81	26437	26637

E15.5mT	**s_o [mm]**	**0s [mm]**	**$S_{deformed}$ [mm]**	**X [mm]**
E15.5T/0	15970	8	15962	16162
E15.5T/1	16066	12	16054	16254
E15.5T/2	16100	16	16084	16284
E15.5T/3	16100	19	16081	16281
E15.5T/4	16100	23	16077	16277
E15.5T/5	16100	27	16073	16273
E15.5T/6	16100	31	16069	16269

Arch Outside Spans: C30T - C54T



C30T	s_o [mm]	0s [mm]	$S_{deformed}$ [mm]	X [mm]
C30T/0	9458	2	9456	9656
C30T/1	9566	4	9562	9762
C30T/2	9630	5	9625	9825
C30T/3	9652	7	9645	9845
C30T/4	9652	8	9644	9844
C30T/5	9652	10	9642	9842
C30T/6	9652	11	9641	9841
C30T/7	9652	13	9639	9839

C36T	s_o [mm]	0s [mm]	$S_{deformed}$ [mm]	X [mm]
C36T/0	11370	4	11366	11566
C36T/1	11460	7	11453	11653
C36T/2	11514	9	11505	11705
C36T/3	11530	12	11518	11718
C36T/4	11530	14	11516	11716
C36T/5	11530	17	11513	11713
C36T/6	11530	19	11511	11711
C36T/7	11530	22	11508	11708
C36T/8	11530	24	11506	11706
C36T/9	11530	27	11503	11703

C42T	s_o [mm]	0s [mm]	$S_{deformed}$ [mm]	X [mm]
C42T/0	13274	7	13267	13467
C42T/1	13350	10	13340	13540
C42T/2	13396	14	13382	13582
C42T/3	13412	17	13395	13595
C42T/4	13412	20	13392	13592
C42T/5	13412	24	13388	13588
C42T/6	13412	27	13385	13585
C42T/7	13412	30	13382	13582
C42T/8	13412	34	13378	13578
C42T/9	13412	37	13375	13575

C54T	s_o [mm]	0s [mm]	$S_{deformed}$ [mm]	X [mm]
C54T/0	16730	10	16720	16920
C54T/1	16862	13	16849	17049
C54T/2	16970	17	16953	17153
C54T/3	17054	20	17034	17234
C54T/4	17112	23	17089	17289
C54T/5	17148	27	17121	17321
C54T/6	17120	30	17090	17290

Appendix B

Compressive Strength Requirements for Cast-in-place Crown Joint Concrete

(Twin-Leaf Arches)

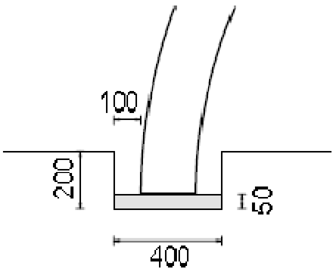
Unless otherwise specified in the drawings, the required cylinder compressive strengths (28 days) for the cast-in-place crown joint concrete are as follows:

Arch Type	f_c' [N/mm^2]
E54T – E72T	40
E78T – E84T	45
C30T	35
C36T – C42T	45

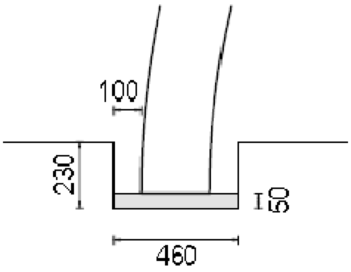
Appendix C

BEBO E and C Series keyway dimensions:

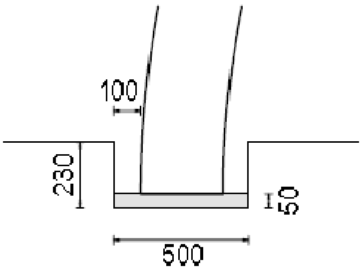
Types E12 through E24



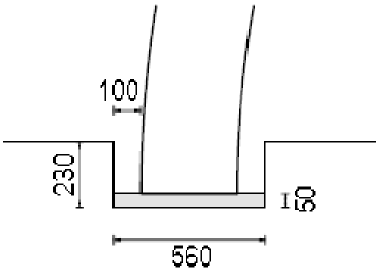
Types E30 through E48 (incl. C30T, C36T)



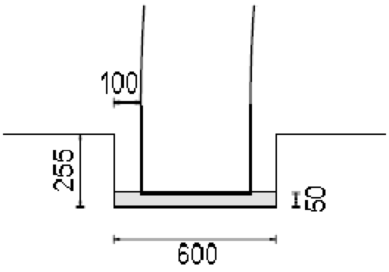
Types E54T, C42T



Types E60T, E66T



Types E72T, E78T



Type E84T