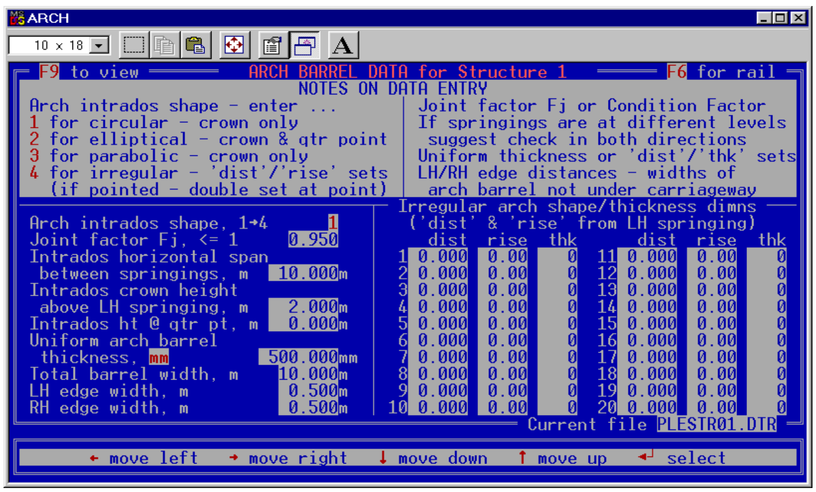
Cascade Software Limited

CIVIL & STRUCTURAL ENGINEERING SOFTWARE

*** ARCH ***

Product Information



Version 4.6
1 November 2001

HELPLINE 01483 811202

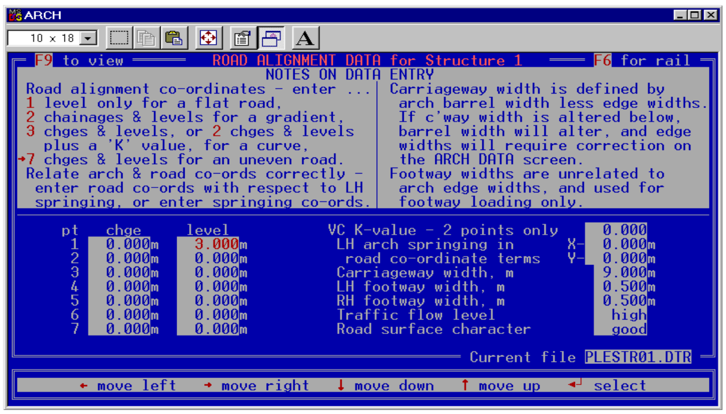
Cascade Software Limited
Brixbury House
Down Lane, Compton
Guildford, Surrey GU3 1DQ

PRODUCT INFORMATION

***** ARCH ***** is a specialist masonry arch analysis program for both highway and rail bridges, based on the Mechanism Method but also providing facilities to carry out Modified MEXE Method analysis and, by seamless link to the parallel program ***** ANALYSE ***** , to undertake Pippard/MEXE frame analysis. The output from ***** ARCH ***** also provides the necessary information for multispan analysis. Like all Cascade programs, ***** ARCH ***** is designed to be easy to understand and use, with a maximum of visible reference information on-screen and a minimal need for reference to the program manual. Graphical views are available at any time at the touch of a key, and results printouts are as neat and informative as we can make them.

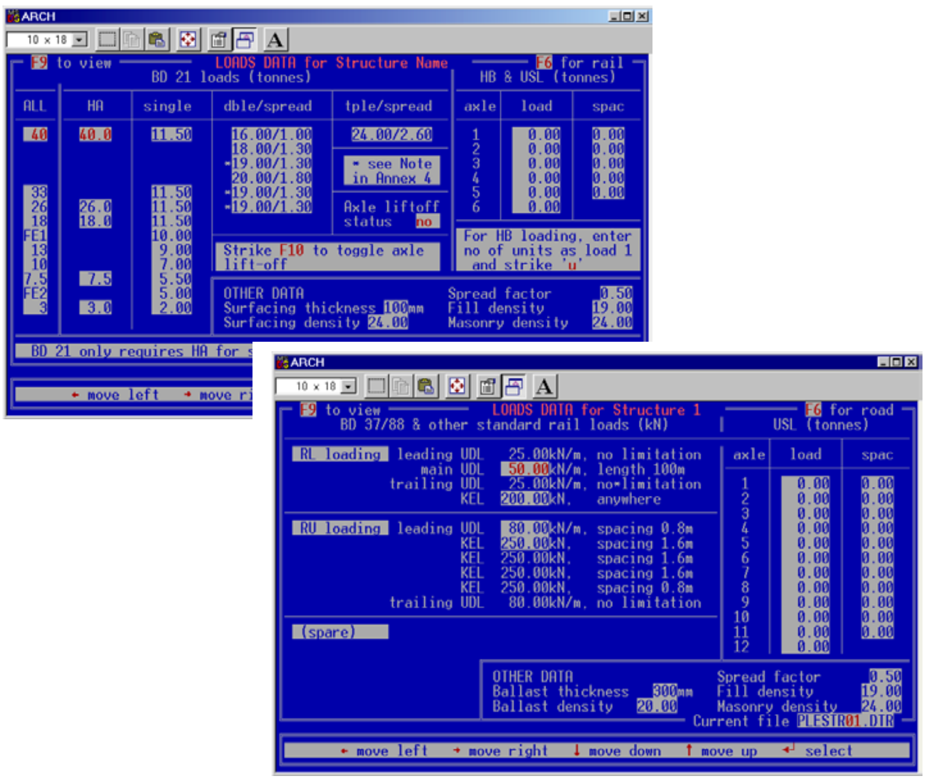
***** ARCH ***** is directed primarily at bridge authorities and consulting engineers engaged in assessing masonry or unreinforced concrete arch bridges. It is designed specifically to respond to the requirements of the Highway Agency's Standards BD 21, BA 16 and BD 37, and Railtrack's Standard RT/CE/C/015, but it can also be used to assess bridges carrying other types of loading specified by the user. Version 4.6 is updated in accordance with BD 21/01.

***** ARCH ***** was developed and tested over several years by the firm of consulting engineers whose computer program for the application of the Mechanism Method to the analysis of masonry arches was first to be recognised by the then DoT. It has been substantially upgraded and extended in line with updated Standards and user experience since its initial launch as Version 2 in 1991.



***** ARCH ***** works iteratively, moving the load pattern automatically across the structure until it discovers the most adverse location. It reports in terms of the Geometric Factor of Safety (GFOS) of the arch at the worst hinge location. Alternatively, it will modify any load pattern pro rata to produce a specific GFOS (usually 1 for unfactored or 2 for factored loads) which is specified before starting by the user. Thus it can either report the response of the bridge to the applied loading, or, by predetermining the required GFOS, the change in that loading to produce collapse. It also provides for fixed load position analysis, in order to be able to parallel the full scale tests and generate data for Pippard/MEXE analysis.

All conceivable shapes of arch and types of road or rail alignment are provided for, including irregular and pointed arches, and varying arch barrel thicknesses, using curve fitting techniques. Loads may be Assessment Live Loading HA or single, double or triple axle, all as BD 21, the HB vehicle with associated HA loading or RL and RU railway loading as BD 37, or user selected axle loads at varying spacing. Footway/verge loading may be added in, and the applied loads may be switched on or off in the various lanes/tracks across the bridge. The arch, road/rail, loads, thrust line and hinges can be viewed at any appropriate stage by use of a 'hot' key, and an instant BA 16 or Railtrack MEXE analysis is available on-screen. Full or abbreviated customised Mechanism or MEXE results suitable for direct report inclusion may be printed out on conclusion or filed for later printing. Version 4 adds the facility for printing semi-graphical distorted scale views of arch, thrust line, hinges, road and load arrangement. If a fixed position analysis has been carried out, then the program provides for the generation of data files for Pippard/MEXE frame analysis, and a seamless link to ***** ANALYSE ***** to undertake and print out the results of that analysis.



PRINCIPAL FEATURES

- a lightning fast DOS program which runs under Windows 95/98/2000/Me in a customisable DOS window – run ***** ARCH ***** from the Taskbar, put a shortcut on the desktop or a button in the button bar
- full built-in range of arch shapes –
  - semi-circular or segmental
  - elliptical or parabolic
  - irregular (levels as measured on site), including pointed
- arch thickness may be uniform or varying with each shape type
- road/rail profile over the arch may be flat, a gradient, a vertical curve or uneven
- full built-in range of prescribed and user loads
  - all BD 21 Assessment Live Loads, ie single (including FE), double and triple axles, with/without liftoff, plus HA UDL and KEL
  - HB vehicle together with HA in other lanes as required
  - RL and RU BD 37 railway loading, and proportions thereof
  - user specified axle loads at varying spacings
  - footway/verge loading, in combination with any of the above
- full control of transverse loading across the bridge, footways/verges, lanes/tracks, widths and lane factors, and the loads applied to each, including user loads
- deals with loaded cantilevered parapets
- loads spread longitudinally and transversely as BD 21, with optional variation in longitudinal load spread
- variable surfacing thickness, surfacing, fill and arch masonry densities
- all BD 21 factors, constants and options fully customisable in program setup
- 3 different types of analysis
  - BD 21, with dead and imposed loads factored
  - BD 21, with imposed loads only factored (usually the worse case)
  - no dead or imposed factors applied
- 3 different iteration types
  - single iteration, to determine Geometric Factor of Safety (GFOS) for a particular load pattern
  - double iteration, varying the load pattern pro rata to achieve a pre-determined GFOS (usually 1 for a collapse load)
  - fixed load position iteration, for generation of Pippard/MEXE data files
- after fixed position iteration, automatic creation of data files for Pippard/MEXE analysis by seamless link to ***** ANALYSE ***** from main Menu
- passive pressure of fill over arch barrel may be varied according to type of material (and optionally with degree of displacement), or ignored
- crushing strength of the arch barrel may be varied between 0 and 99N/mm^2, or ignored
- full MEXE segment for both road and rail bridges with instant recalculation - summary BA 16 and RT/CE/C/015 reference Tables available on-screen
- full graphical views of arch, road/track, loads, thrust line and hinge positions by striking the 'F9' key at any time
- all arch, road/track and MEXE data may be saved to file and recalled - up to 99 data files per structure with optional auto backup and prompt
- data and results files may be copied, renumbered or deleted, and backup files restored, within the program
- comprehensive display customisation, printer and technical setup facilities
- full range of customised printout options, including semi-graphical plots of arch, thrust line, hinges, road/rail alignment and arrangement of loads
- output provides necessary data for multispan pier analysis calculations
- print to file and print from file, as well as direct printing to printer

VALIDATION INFORMATION

Sections 6.l8 – 6.20 of BD 21 comment inter alia on the use of γ_{fl}, commonly known as the uncertainty factor, and suggest a value of 1.0 when the method being used has been validated against full scale test results such as those organised in recent years by TRL & others. Annex E, Table E2 of BA 16 compares predicted failure loads from various analysis sources, including ***** ARCH ***** Version 2, with the failure loads resulting from these tests. In the Table below we supply in addition the results of analysing the TRL bridges with ***** ARCH ***** Version 4.6.

The TRL results appear in the first two columns. These are essentially fixed position collapse loads, and do not therefore necessarily represent the lowest possible collapse load for the structure. In these tests it was only possible to obtain a single result, and the load was positioned by informed judgement in what was considered to be the worst position. Fixed position analyses by ***** ARCH ***** are shown in columns three and four, column three using a Joint Factor based on the as-reported condition of the bridge and column four using a Joint Factor of unity. The closest comparison should therefore be between columns two and three. The final four columns show the results of full double iteration analyses by ***** ARCH ***** with the alternative Joint Factor values, and indicate where the worst load positions are located, and how much lower the collapse loads might well have been.

The results for ***** ARCH ***** although conservative compare well with other methods. A closer approach to the actual collapse loads may be achieved by increasing the assumed passive pressure of the fill, and by adopting higher masonry crushing values. This is an area where engineering judgement has to be applied. The TRL bridge details are supplied with both DEMO and substantive versions of the program to allow the engineer to explore the effects of varying parameters thus.

bridge	Load position **fixed**				Load position **varied**			
	TRL		***** ARCH *** V4.6**		***** ARCH *** V4.6**			
			Fj = CF	Fj = 1	Fj = CF		Fj = 1	
	position	test load	load	load	position	load	position	load
Bridgemill	25	**310**	**215**	231	20	200	19	217
Bargower	33	***560***	**647**	685	30	632	33	685
Preston	33	**210**	**115**	156	28	113	29	154
Prestwood	25	**22**	**2**	11	17	2	18	9
Torksey	25	**108**	**88**	115	20	88	21	113
Shinafoot	n/a	**250**	n/a	n/a	21	**198**	21	214
Strathmashie	n/a	**132**	n/a	n/a	28	**133**	28	230
Barlae	n/a	**290**	n/a	n/a	20	**162**	20	209
Dundee	n/a	**104**	n/a	n/a	31	**70**	31	70
Bolton	n/a	**117**	n/a	n/a	20	**46**	20	46

Notes on the Table:
All loads in tonnes.
Bold figures represent the most closely comparable conditions.
'position' is the distance across the bridge to the load in 1/100ths of the span.
'Fj' = Joint Factor, 'CF' = Condition Factor as reported by TRL
Bargower bridge gave trouble during test loading, the load was recycled several times before failure, and the true collapse load is reckoned to be higher.
Dundee and Bolton were full scale models.
Barlae skew was 29^0, Bargower and Preston also had significant skews – skew increase collapse loads.
Prestwood is described as 'deformed', but clearly the CF of 0.5 is unrealistically low.

ANALYSIS SUMMARY

Type 2 analysis, BD 21 single axle loading, only imposed loads factored, allowing for fill passive pressure and allowing for crushing of arch barrel masonry.
Single iteration to determine Geometrical Factor of Safety (GFOS) of arch barrel.

ARCH DATA

Barrel intrados shape:	segmental
Uniform thickness of barrel normal to arch:	0.500m
Horizontal span between springings at intrados:	10.000m
Vertical height of intrados crown above LH springing:	2.000m
Barrel width dimensions (LH edge/c'way/RH edge):	0.500/9.000/0.500m
Joint Factor (generally as defined in BA 16/97):	0.950 (applied to the arch barrel thickness)
Assumed barrel masonry crushing strength	5.0N/mm2
Fill passive pressure K factor:	allowed 3.00, used 3.00
Uncertainty (F3) factor (validated program):	1.00

ROAD DATA

Alignment over arch:	flat
Level at crown (above LH springing):	3.000m
Cross-section dimensions (LH footway/c'way/RH footway):	0.500/9.000/0.500m
Traffic flow level:	*high*
Road surface category:	Poor

LOADS DATA

Dead Loads:	density (kN/m3)	load factor
Road surfacing 100mm *thick:*	24.00	1.00
Fill over arch:	19.00	1.00
Arch barrel masonry:	24.00	1.00

Imposed Loads:

40.0 tonnes ALL single axle loading, no liftoff, axle load 11.50 tonnes

lane	width(m)	factor	loading	load/axle/lane(t)	factors	conversion factors	appl load/axle/lane(t)
LH	0.500	N/A	footway	(5.000kN/m2)	1.50	N/A	(3.750kN/m)
1	2.500	1.000	single axle	11.500	3.40	1.00	39.100
2	2.500	1.000	single axle	11.500	3.40	1.00	39.100
3	2.500	1.000	single axle	11.500	3.40	1.00	39.100
RH	2.000	N/A	footway	(5.000kN/m2)	1.50	N/A	(15.000kN/m)

Total imposed single axle loads 117.300t

RESULTS

The axle has been advanced across the arch for a horizontal distance of 2.25m (on segment 23)
Iterated final mechanism details are as follows:-

hinge no	*between segments*	*thrust (kN)*	*barrel thk x Fj (mm)*	*reduced by (mm)*	*nett thk (mm)*
1	1s & 1	4085	475	54	421
2	24 & 25	3090	475	41	434
3	54 & 55	2922	475	39	436
4	*92 & 93*	*2439*	475	*33*	*442*

Vertical reactions, at hinge 1 2860kN, at hinge 4 1377kN
Horizontal reactions, at hinge 1 2917kN, at hinge 4 2013kN
Total passive pressure reaction between hinges 3 & 4 904kN

The Geometric Factor of Safety is defined as the ratio of the actual arch thickness to that required just to contain the line of thrust fully:

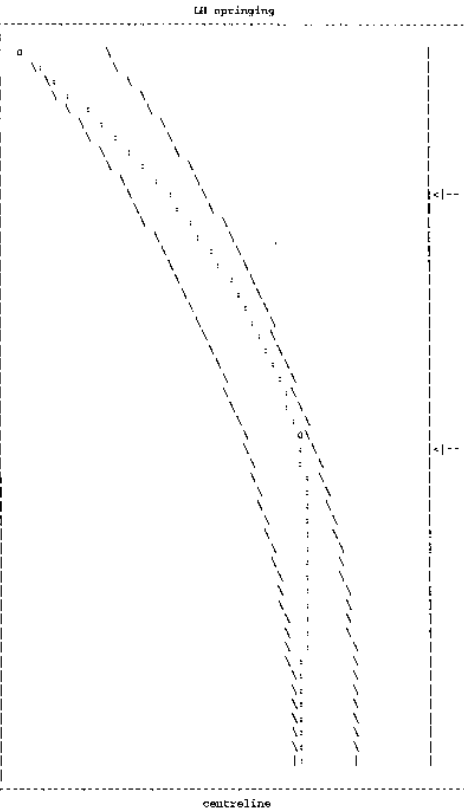
The GEOMETRIC FACTOR OF SAFETY RESULTING FROM THIS ANALYSIS is 1.46

P R O J E C T   N A M E
Mechanism Method Masonry Arch Analysis by *** ARCH *** v4.60
STRUCTURE 1

Job no: Example
file no: PLESTR01.DTR
11:35 23 October 2001

SEMI-GRAPHICAL PLOT OF ARCH, ROAD, LOAD & THRUSTLINE GEOMETRY

hinge/ axle no	point no/ distance	in'dos	thrust line	ex'dos	road
hinge 1	0/ 0.000	0.000	0.000	0.638	3.000
	1/ 0.100	0.093	0.126	0.721	3.000
	2/ 0.200	0.183	0.250	0.802	3.000
	3/ 0.300	0.270	0.371	0.880	3.000
	4/ 0.400	0.354	0.487	0.956	3.000
	5/ 0.500	0.434	0.598	1.028	3.000
	6/ 0.600	0.512	0.705	1.099	3.000
	7/ 0.700	0.587	0.807	1.167	3.000
	8/ 0.800	0.660	0.904	1.233	3.000
	9/ 0.900	0.729	0.997	1.297	3.000
axle 2	10/ 1.000	0.797	1.085	1.358	3.000
	11/ 1.100	0.862	1.169	1.418	3.000
	12/ 1.200	0.924	1.249	1.475	3.000
	13/ 1.300	0.985	1.325	1.531	3.000
	14/ 1.400	1.043	1.396	1.585	3.000
	15/ 1.500	1.099	1.463	1.636	3.000
	16/ 1.600	1.153	1.526	1.686	3.000
	17/ 1.700	1.205	1.586	1.734	3.000
	18/ 1.800	1.256	1.642	1.781	3.000
	19/ 1.900	1.304	1.694	1.826	3.000
	20/ 2.000	1.350	1.744	1.869	3.000
	21/ 2.100	1.395	1.792	1.910	3.000
	22/ 2.200	1.437	1.838	1.950	3.000
	23/ 2.300	1.478	1.883	1.988	3.000
	24/ 2.400	1.518	1.925	2.024	3.000
	25/ 2.500	1.555	1.964	2.059	3.000
	26/ 2.600	1.591	1.998	2.093	3.000
hinge 2	27/ 2.700	1.625	2.027	2.125	3.000
axle 1	28/ 2.800	1.658	2.051	2.155	3.000
	29/ 2.900	1.689	2.070	2.184	3.000
	30/ 3.000	1.719	2.084	2.212	3.000
	31/ 3.100	1.747	2.093	2.239	3.000
	32/ 3.200	1.773	2.099	2.262	3.000
	33/ 3.300	1.798	2.100	2.286	3.000
	34/ 3.400	1.821	2.099	2.307	3.000
	35/ 3.500	1.843	2.097	2.328	3.000
	36/ 3.600	1.864	2.095	2.347	3.000
	37/ 3.700	1.882	2.093	2.365	3.000
	38/ 3.800	1.900	2.090	2.381	3.000
	39/ 3.900	1.916	2.087	2.396	3.000
	40/ 4.000	1.931	2.084	2.410	3.000
	41/ 4.100	1.944	2.081	2.422	3.000
	42/ 4.200	1.956	2.077	2.433	3.000
	43/ 4.300	1.966	2.073	2.443	3.000
	44/ 4.400	1.975	2.068	2.452	3.000
	45/ 4.500	1.983	2.063	2.459	3.000
	46/ 4.600	1.989	2.058	2.465	3.000
	47/ 4.700	1.994	2.052	2.469	3.000
	48/ 4.800	1.997	2.046	2.472	3.000
	49/ 4.900	1.999	2.039	2.474	3.000
	50/ 5.000	2.000	2.032	2.475	3.000



Approximate scales - height 1: 33 , span 1: 31
Note that for clarity the thrust line has been plotted relative to the arch intrados - the 'spare' barrel thickness above hinges 2 and 4 is a measure of the Geometrical Factor of Safety.

Railtrack — Job no: Example
BD 37 Mechanism Method Masonry Arch Analysis by *** ARCH *** v4.00 — file no: PLERAI00.DTR
RAILTRACK EXAMPLE — 15:11 23 October 2001

ANALYSIS SUMMARY
Type 2 analysis, BD 37 RU loading, only imposed loads factored, allowing for fill passive pressure and allowing for crushing of arch barrel masonry.
Single iteration to determine Geometrical Factor of Safety (GFOS) of arch barrel.

ARCH DATA

Barrel intrados shape:	circular
Uniform thickness of barrel normal to arch:	0.686m
Horizontal span between springings at intrados:	12.192m
Vertical height of intrados crown above LH springing:	6.096m
Barrel width dimensions (LH edge/track/RH edge):	0.500/5.500/0.500m
Joint Factor (generally as defined in RT/CE/C/015):	0.950 (applied to the arch barrel thickness)
Assumed barrel masonry crushing strength	5.0N/mm2
Fill passive pressure K factor:	allowed 3.00, used 3.00
Uncertainty (F3) factor (validated program):	1.00

RAIL DATA

Alignment over arch:	flat
Level at crown (above LH springing):	7.583m
Cross-section dimensions (LH verge/track/RH verge):	0.500/5.500/0.500m

LOADS DATA

Dead Loads:	density (kN/m3)	load factor
Rail ballast 300mm thick:	20.00	1.00
Fill over arch:	19.00	1.00
Arch barrel masonry:	24.00	1.00

Imposed Loads:
RU loading, 4No KEL's of 250kN/track @ 1.6m centres followed 0.8m by UDL of 80kN/m of track
(load factors: imposed load 1.40 / dynamic, varied with 0.5xspan of 12.19m, 1.62 / F3 1.00)

track	width(m)	factor	loading	UDL(kN/m/track)	4xKEL(kN/track)	factors	UDL(kN/m/track) applied	4xKEL(kN/tr'k)
LH	0.500	N/A	none	N/A	N/A	2.27	N/A	N/A
1	2.750	1.000	RU	80.000	4x250.000	2.27	181.391	4x566.846
2	2.750	1.000	RU	80.000	4x250.000	2.27	181.391	4x566.846
RH	0.500	N/A	none	N/A	N/A	2.27	N/A	N/A

Total RU loads — UDL 362.781kN/m 4xKEL1133.692kN

RESULTS
The RU leading KEL has been advanced across the arch for a horizontal distance of 3.78m (to segment 31);
the three following KEL's are 1.6/3.2/4.8m behind the leading KEL (on segments 18/ 5/ -8 respectively),
(any negative values are off the bridge).
Iterated final mechanism details are as follows:-

hinge no	between segments	thrust (kN)	barrel thk x Fj (mm)	reduced by (mm)	nett thk (mm)
1	14 & 15	3136	652	64	587
2	33 & 34	2289	652	47	605
3	56 & 57	2196	652	45	606
4	84 & 85	1785	652	37	615

Vertical reactions, at hinge 1 2251kN, at hinge 4 1193kN
Horizontal reactions, at hinge 1 2183kN, at hinge 4 1327kN
Total passive pressure reaction between hinges 3 & 4 856kN

The Geometric Factor of Safety is defined as the ratio of the actual arch thickness to that required just to contain the line of thrust fully:

The GEOMETRIC FACTOR OF SAFETY RESULTING FROM THIS ANALYSIS is 2.06