CAP 2021 version notes

A revised version of the Culvert Analysis Program (CAP) (version 2021) is available that addresses several known errors in previous versions of the software. CAP version 2021 will be available as a computational solver in version 4 of the International River Interface Cooperative (iRIC) numerical simulation platform (available at https://i-ric.org/) and as a standalone program. Most of the updates correct known errors (mostly minor) with discharge computations for culverts, as documented in Techniques of Water-Resources Investigations of the United States Geological Survey, book 3, chapter A3, "Measurement of Peak Discharge at Culverts by Indirect Methods" (Bodhaine, 1968). A detailed list of the errors corrected can be found in the CAP error resolution summary. Users of the CAP version 2021 software also should be aware of the following updated guidance.

Ordering of specific CAP records in the input file

For computations using the standalone version of CAP, the following records (if included in the input file) must be ordered in the input as follows (though not necessarily in series): *C1, *C5, *C3, then *CC. This ordering requirement is not specified in the User's guide to the U.S. Geological Survey Culvert Analysis Program, version 97-08 (Fulford, 1998), but is necessary for the CAP operating rules to function correctly. The iRIC input routines automatically order these records correctly.

Clarifications of the culvert material codes (J code in the CG record)

Construction material and characteristics of the culvert must be identified correctly in the field. Construction material used for metal pipe arches also must be identified as either corrugated metal (non-plate) pipe arches (CMPA) or corrugated metal structural-plate pipe arches (CMSPPA). For example, see the North Carolina Department of Transportation Culvert Identification Field Guide (North Carolina Department of Transportation, 2021).

Additional descriptive information for each culvert material code is provided below to aid the user in field identification. Material codes 1-6 function like those documented in the User's Guide to the U.S. Geological Survey Culvert Analysis Program, version 97-08 (Fulford, 1998). Material code 7 was added to support a culvert material not previously specified in CAP. Note that where a corner rounding radius (CORRAD) is specified, unentered rounding radii are estimated based on the assumption that the pipe arch has the indicated CORRAD.

Material code (J) – Description

1 – Concrete pipe

2 – Corrugated metal or other pipe (not concrete)

3 – (CMSPPA) Aluminum pipe arch with CORRAD = 31.75 inches (9" x 2-1/2" corrugations)

4 – (CMSPPA) Corrugated steel pipe arch with CORRAD ≤ 18 inches (2-2/3" x 1/2" corrugations)

5 – (CMSPPA) Corrugated steel pipe arch with CORRAD = 31inches (6" x 2" corrugations)

6 – (CMSPPA) Corrugated steel pipe arch with CORRAD = 47" (6" x 2" corrugations)

7 – (CMPA) Non-plate corrugated steel pipe arch (includes pipes with 2-2/3" x 1/2", 3" x 1", and 5" x 1" corrugations, and spiral and composite ribbed pipe arches)

Clarifications for the analysis of circular and elliptical culverts

For circular and elliptical pipe culverts (shape code I=2 in the CG record), the user can select material code J=1 (concrete pipe) or J=2 (corrugated metal or other pipe (not concrete)), depending on the material composition of the culvert. The inlet type and observed inlet geometric characteristics or discharge coefficient adjustments must be specified (use the *CC or *C3 and *C5 records when using the standalone version). See the User's Guide to the U.S. Geological Survey Culvert Analysis Program, version 97-08 (Fulford, 1998) for more information.

Updates and clarifications for the analysis of pipe-arch culverts

Pipe-arch construction for metal pipe arches must be identified in the field as either concrete, corrugated metal non-plate pipe arches (CMPA), or corrugated metal structural plate pipe arches (CMSPPA). For example, see the North Carolina Department of Transportation Culvert Identification Field Guide (North Carolina Department of Transportation, 2021).

The user can specify 0, 1, 2, or 3 of the pipe-arch radii measurements; however, measurement recommendations for specific types of standard pipe-arch culverts are as follows.

- **Concrete pipe (J=1)**: It is recommended that the CORRAD be measured directly for concrete pipe-arch culverts. The measurement will improve estimates of the other radii.
- **(CMSPPA) Aluminum pipe arch with CORRAD = 31.75 inches (J=3)**: Aluminum pipe (CMSPPA, J=3): CAP defaults Option assumes a CORRAD to 31.75 inches". The bottom rounding radius (BOTRAD) should be measured and entered to ensure the most accurate estimates (by CAP) of pipe-arch dimensions. This is especially important for rises < 103".
- **(CMSPPA) Corrugated metal pipe (CMSPPA) with CORRAD ≤ 18" (J=4)**: Entry of measured CORRAD is recommended. If CORRAD is not specified, a CORRAD of 18" is used if the rise is greater than or equal to 55" and is estimated by the program if the rise is less than 55".

- **(CMPA) Non-plate corrugated metal pipe (J=7)**: Both the CORRAD and BOTRAD should be measured at the site. If no measurement is entered for CORRAD, it will be estimated based on the span when the SPAN ≤ 57" or ≥ 87". For 57" > SPAN < 87", CORRAD is assumed to be 21". If no measurement is entered for BOTRAD, it will be estimated based on the CORRAD; however, the estimate could be in error by as much as 21 percent.

Standard pipe-arch dimensions (on which the computations are based) can be found in the Hydraulic analysis of pipe-arch and elliptical shape culverts using programable calculators (FHWA, 1982), the Structural Plate Design Guide (Contech, 2021) and the Corrugated Steel Pipe Design Manual (National Corrugated Steel Pipe Association, 2017).

Following are some additional notes regarding mitered pipe-arch culverts:

- The inlet type and observed inlet geometric characteristics or discharge coefficient adjustments can be specified (use the *CC or *C3 and *C5 records when using the standalone version). See the User's Guide to the U.S. Geological Survey Culvert Analysis Program, version 97-08 (Fulford, 1998) for more information.
- Mitering of any pipe-arch type can be specified by setting the INLET code (use the *CC or *C3 record in the standalone version) to 2 (mitered end).
- The effective length of a mitered culvert can be determined by entering the relevant measurements in the iRIC Alignment menu for Mitered culvert or can be computed/entered manually by the user (see the CVLENG explanation on page 15 of User's Guide to U.S. Geological Survey Culvert Analysis Program, version 97-08 (Fulford, 1998)).

Pipe-arch culverts with measured dimensions (in particular, rise and span) that are outside the range of standard dimensions for that culvert type are flagged with a warning in the CAP output and should not be analyzed using the shape code I=3; nonstandard rise/span combinations can produce inaccurate estimates by CAP of other necessary culvert dimensions (for example, BOTRAD and TOPRAD). Instead, pipe-arch culverts with nonstandard rise/span dimensions should be analyzed using a shape code I=4 (non-standard shape), which requires that the culvert geometry be measured and entered as x-y point coordinates. Note that any pipe-arch culvert can be analyzed using a shape code I=4 (non-standard shape), if desired.

CAP User's Guide omissions and errors (identified during 2021 review)

1. For computations using the standalone version of CAP, the following records (if included in the input file) must be ordered in the input as follows (though not necessarily in series): *C1, *C5, *C3, then *CC. This ordering requirement is not specified in the CAP User's Guide (Fulford, 1998), but is necessary for the CAP operating rules to function correctly. The iRIC input routines automatically order the records correctly.

2. *CC record (p. 17): Figure citation for variable 'W' should be figure 22, pg. 40 (not "figure 24, pg. 40").

3. *CC record (p. 17): Third sentence for variable 'W' should read "If bevel width, W, is greater than **or equal to** 0.1 times the culvert diameter, depth, or width, the bevels are considered to act as a wingwall.

4. Example computation for multiple culvert openings – Rio Grande conveyance channel (pp. 43-50): Corrected pipe-arch dimensions (J codes) in CAP 2021 indicate that the culverts in this example are non-standard and should not be computed using the pipe-arch shape code I=3. The shape code for non-standard culvert (I=4), along with measured X-Y point coordinate geometry), is needed to correctly analyze these culverts.

5. Example computation using new records – Example Creek, TWRI example 8 (pp. 58-61): CAP 2021 corrects computational errors in previous versions of CAP. The minimum approach-section elevation of 1.951 m (6.4 ft) and corrected fall, loss, and velocity-head values are displayed in the output table.

References

Bodhaine, G.L., 1968, Measurement of peak discharge at culverts by indirect methods: U.S. Geological Survey Techniques of Water-Resources Investigations, book 3, chap. A3, 60 p., accessed December 2021 at https://pubs.usgs.gov/twri/twri3-a3/pdf/TWRI_3-A3.pdf

Contech, 2021, Structural Plate Design Guide – 7th Edition, 120 p., accessed December 2021 at https://www.conteches.com/Portals/0/Documents/Design%20Guides/SPDG.pdf?ver=2018-06-15-105957-787

Federal Highway Administration, 1982, Hydraulic analysis of pipe-arch and elliptical shape culverts using programable calculators, Calculator design series no. 4, variously paginated

Fulford, J.M., 1998, User's guide to the U.S. Geological Survey Culvert Analysis Program, Version 97–08: U.S. Geological Survey Water-Resources Investigations Report 98–4166, 70 p., accessed December 2021 at https://pubs.usgs.gov/wri/1998/4166/report.pdf

National Corrugated Steel Pipe Association, 2017, Corrugate Steel Pipe Design Manual, 624 p., accessed December 2021 at https://ncspa.org/ncspa-csp-design-manual-survey/

North Carolina Department of Transportation, 2021, Culvert Identification Field Guide, 15 p., accessed December 2021 at https://connect.ncdot.gov/resources/hydro/Hydraulics%20Memos%20Guidelines/Culvert_Identification_Field_Guide.pdf