DESIGN AND CONSTRUCTION FEATURES CONCERNING THE RING COMPRESSION THEORY, AS APPLIED TO CORRUGATED STRUCTURAL PLATE STEEL PIPE *

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Most of us, as Civil Engineers, make use of familiar formulae, reference tables, data and the like, in our daily design work and field engineering, with repeated usage of tested methods the general rule. So, it is most welcome to find a new method or approach in the use of a familiar material, something we can study, evaluate and adapt to our own uses. This part of our presentation deals with such a relatively new approach — the "Ring Compression" method of design for corrugated steel pipe structures.

Basically, we consider two strength requirements when designing for corrugated steel pipe to carry normal loading upon the cross section of the pipe. One consideration is the compressive strength to take care of the dead and live loads, and the other is the "moment" strength, or handling strength necessary to allow the pipe to be properly installed and backfilled.

We have been familiar with the "Gage Tables", such as those developed by ARMCO and found in our design manuals and handbooks — which show recommended minimum gages of plate, versus fill heights and loading conditions, and were based on these same strength requirements. These tables were developed through the observation of the reactions of corrugated steel pipe in many installations throughout the country since around 1900. Much was also learned from actual experimentation such as the load tests carried out at Iowa State College by Dean Marston of the Engineering Faculty. These Gage Tables are still quite valid and are in general use today.

In more recent years, the "Ring Compression" method of design was conceived and developed, primarily for use with structures beyond the existing Gage Tables in terms of size of structure and fill height. A paper covering this design method, titled: "The Corrugated Metal Conduit as a Compression Ring", was presented at the 39th Proceedings of the Highway Research Board, in Washington, D.C., by Howard White and J. P. Layer of ARMCO.

An early test installation, based on this design concept, in Saskatchewan, utilized a six-foot diameter structure in the ½″ deep corrugation of 20-

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gage material under a 33 foot fill. The 20-gage sheet is about as thick as a thin dime. More recently, structures in multi-plate have been installed, such as a 24-foot diameter pipe under railroad yard tracks at Newport, Kentucky.

Ring compression is a term here applied to a corrugated steel pipe which has been properly installed and backfilled to a height over the pipe of at least one-quarter its diameter. Under this vertical fill loading the pipe has developed side support from the fill and has reached a state of equilibrium.

SLIDE #1 —

When the pipe has thus been put into ring compression, the measure of strength with which we are concerned is the longitudinal seam strength in the pipe wall. Further, when strength design is based on ring compression, it is assumed that the pipe will have proper bedding and a well-tamped backfill of suitable material to approximately 95% Proctor will be obtained. This matter of proper installation and backfill will be more thoroughly discussed and illustrated by the film later.

This brings us to the actual steps involved in designing a structure by this method. The loading on the structure is considered to be those forces acting vertically in a plane perpendicular to the longitudinal axis of the structure, these loads produced by the weight of the fill in the column of earth over the structure and a surcharge for live loads. It is generally accepted practice to use a weight of 100# per cubic foot of earth for the average compacted roadway embankment, and the intensity in pounds per square foot for the live load transmitted to the plane across the top of the structure. For fill heights greater than approximately eight feet the live load is disregarded for H-20 loading. Tabular values for these dead and live loads are readily available in standard handbooks.

With this loading determined, it is then a simple calculation to compute the vertical component of pressure in the ring by multiplying (100 × height of cover plus live load in pounds per square foot) times one-half the structure's diameter, for round pipe, or times one-half the span for a pipe-arch. This gives the compressive load in pounds per foot of longitudinal wall seam.

SLIDE #2

Next, having determined the compression per foot in the ring, we apply a factor of safety of four (4) where average fill materials and backfill practices can be expected. With this value of four times the compression load per foot of seam we then refer to the tabular values for safe seam strengths, versus gage of plate and bolting pattern — and select the plate gage which gives us at least this design value for seam strength. For some carefully controlled and well-engineered installations, a safety factor of two has been used and found to be adequate, but this is strictly limited to the category of special installations.

SIDE #3

It is usual practice to check the reaction pressures against soil bearing capacity and this can be readily accomplished by equating the design ring compression load to the product of the plate curvature radius in feet and the pressure per square foot. As an example, we would equate ring compression "C" TO Pc X Rc and SOLVE FOR Pc. This is particularly necessary in connection with pipe-arch structures which have a sharp radius corner plate that develops high unit pressures under the haunches of the structure. This may well become a problem requiring the soils engineer to recommend proper treatment of this area of the foundation.

A further consideration in design is the so-called "Flexibility Factor" of the structure. This is an indicator for "moment" strength or handling strength, which must be adequate to allow for resistance to deformation or buckling during the backfilling operation. Safe values are based on the existing gage tables which have been in use for many years. The factor is computed by dividing the square of the pipe diameter in inches by the moment of inertia of the pipe wall in inches ^{4}, or D^2/I, using standard tabular values for I. For structural plate steel pipe the factor should not exceed 6.0×10^5.

This covers briefly the design phase and brings us to the equally important consideration of proper installation and backfilling of the structure.

We can gain the economic advantages of these larger multi-plate structures if they are properly installed — and proper installations can be obtained with no more than our *normal* specifications, when these are thoroughly carried out in the field.

First, the foundation should be checked to avoid the presence of soft or compressible material too close to the structure and consequent settlement of the invert, or the presence of rock or hard spots which create unequal settlements and unequal loads on the structure. Compressible material should be removed and replaced with stable material, such as bank run gravel, and here it is important to note that replacement should not be limited to the width of structure, but should extend either side to a distance of from one-half diameter to a full diameter or span. Rock should be removed to a depth of approximately two feet below invert, and replaced with compacted granular material. For long lines under high fills, camber should be used to obtain a true invert grade after installation. The proper amount of camber is based on analysis of the foundation and loading, normally the province of the soils engineer for recommendations.

Shaped bedding is not usually employed to fit the bottom portion of the structure, as with shovel placing and compactors it is possible to place granular fill under the haunches of the structure and gain the same effect.

Proper assembly of the structure is a must, of course. The correct plate layout and pattern should be adhered to, and where gage combinations are used, the gage and location of different plates should be checked for conformance to plan. Bolts should be uniformly tightened within prescribed torque limits. The assembled structure should have the design dimensions and this should be checked out also.

If we were to single out one most important phase of installation, in our opinion this would be the filling operation. A suitable granular material should be used and the compaction should be equal to that of a properly placed roadway embankment, generally considered to be about 95% Proctor. Particular care should be taken to be certain that material be adequately tamped at the lower part of the structure and under the invert portion.

SLIDE #4

Compacting tampers or rolling equipment should consolidate material in relatively thin layers, uniformly on each side of the structure.

SLIDE #5

Generally these layers should not exceed twelve inches (12″) before compaction. This compaction should be carried beyond three-quarters of the vertical height and should extend on either side for at least one diameter. When the top of the structure is reached, care must be exercised with equipment operations to avoid damage until sufficient depth over the structure will afford protection. This particularly applies to heavy live loading with large earthmoving vehicles in use today. In this connection I quote from the specifications of one of our New England states: "The contractor shall maintain a minimum cover of three feet over all culverts where construction equipment is used or traffic maintained. Whenever the minimum cover material extends above the subgrade line, the contractor will be paid earth excavation for the removal of cover material necessary to complete the work in accordance with the plans. Any deviation from this practice shall have prior approval by the engineer" And further, "it shall be the contractor's responsibility to see that there is adequate earth cover over the structure. . . . Before heavy construction equipment is driven over it". The adherence to this kind of field practice can prevent unnecessary and unwarranted damage to any structure during construction.

We have covered some basic theory here today, and outlined the methods by which we design and *install* a corrugated steel pipe structure under the "Ring Compression" method.

For the designer and the field engineer it is important to bear in mind that with this method, we are building structures of *Earth* and *Steel.*

Next on the program, we will show a short, color and sound film, titled "Structures of Earth and Steel", produced by the ARMCO Steel Corporation.

Thank You.