

INTRODUCTION

Years of dependable service and a multitude of wide ranging installations have led the corrugated steel industry to play a major role in modern engineering technology for drainage systems. Flexible steel conduits play an important role in the form of culverts, storm sewers, subdrains, spillways, underpasses, conveyor conduits, service tunnels, detention chambers and recharge systems; for highways, railways, airports, municipalities, recreation areas, industrial parks, flood and conservation projects, water pollution abatement and many other programs.

Progress Through Research

Engineers and contractors are an imaginative lot, seeking improved ways of designing and building their projects. Steel manufacturers and fabricators have cooperated, through their research and manufacturing staffs, to provide engineers and contractors with better materials, products and installation methods.

Manufacturers' sales staffs and associations are made up largely of experienced professional engineers, knowledgeable in the construction industries problems, who constitute a prime information source on applications, specifications and installation of their products.

Sizes and Shapes

Corrugated steel products are available in a wide range of sizes and shapes for many applications. Round pipe is available in diameters from 150 mm to nearly 16 m. Pipe-arches, long span structures, arches and box culverts are available in many combinations of rise and span up to 23 m.

Structural Strength

Mechanical properties of steel are controlled in the mill, and the finished product is fabricated to exacting specifications. The strength and integrity of soil/steel structures is extremely predictable as the result of current research in laboratory and field installations.

Low Maintenance

Costs of maintaining installations are effectively controlled through modern design criteria for corrosion factors. By proper use of materials for specific locations or applications, utmost economy and optimum service life are assured.

Time Saving

With the huge investment in equipment and the high cost of labor, contractors are always looking for materials and products to help avoid costly delays and speed installation. Strategically located corrugated steel pipe fabricating plants ensure timely deliveries. Temperature extremes and precipitation have little effect on corrugated steel structures, so they can be scheduled for delivery and installation with a minimum of delay. Rapid installation and the inherent strength of steel enable the contractor to make more efficient use of equipment. Heavy earthmovers can operate over corrugated steel structures with adequate cover, a very real savings often overlooked when evaluating corrugated steel against other materials.

Acceptance of Steel

Steel is universally recognized, specified and used as a construction material for corrugated conduits and other products. For many years, these products have been included in standards and specifications published by the Canadian Standards Association (CSA), the American Association of State Highway and Transportation Officials (AASHTO), the American Society for Testing and Materials (ASTM), the Federal Highway Administration (FHWA), the American Railway Engineering and Maintenance-of-Way Association (AREMA), the Corps of Engineers, the Federal Aviation Administration (FAA), the U.S. Forest Service, the Natural Resources Conservation Service (NRCS), as well as provincial, county, township and municipal departments, and well recognized consulting engineers.

STORM DRAINAGE

Generally, drainage facilities can be classified into three major types of construction; culverts, storm sewers and bridges.

Culverts

The distinction between culverts and storm sewers is made mostly on the basis of length and the types of inlets and outlets. A culvert is defined as an enclosed channel serving as a continuation or substitute for an open stream, where that stream meets an artificial barrier such as a roadway, embankment, or levee. Culverts are usually less than 60 m in length.

A culvert may also be classified as a type of bridge. Normally, the rigid definition of a bridge requires that the deck of the structure also be the roadway surface, and simply an extension of the roadway. The use of corrugated steel pipe, large diameter pipe-arches, structural plate, and corrugated steel box culverts have played a major role as replacements for deteriorated bridges and altered this conventional definition.



Highway 401 in Ontario using spiral rib steel pipe and corrugated steel pipe for median drainage.

Storm Sewers and Stream Enclosures

A storm sewer is a collection system for storm water, surface water and street wash, exclusive of domestic and industrial wastes. It is a series of tangent sections with manholes or inlets at all junction points. This water is little, if any, more corrosive than rural watershed runoff. Erosion by the hydraulic traffic may be a factor but normally is less than in culverts.



Combination stream crossing (with relief from flow area) and voids to reduce dead load on foundation soils.

Corrugated steel storm sewers have a service record of over 100 years. The strength, flexibility, positive joints and installation economies of steel storm sewers are assured by the use of rational corrosion design criteria and readily available coatings and linings. Steel storm sewers are also used to re-line failing sewers of all sizes, shapes and materials with a minimum reduction in waterway area.

Many growing communities face the need for expansion in their storm sewer systems to accommodate residential, commercial and industrial developments. Corrugated steel pipe provides a ready solution. Its inherent advantage to contractors, and long range economies for cost-conscious municipalities, enables construction of projects that might not be built otherwise. Open materials competition ensures these communities of the most favorable bid prices possible.

The use of corrugated steel pipe for storm sewers has grown. The product data, design information and engineering considerations for such applications are beyond the scope of this publication. The Corrugated Steel Pipe Institute (CSPI) has published a design handbook entitled *Modern Sewer Design*, which covers proper storm sewer design.

Bridges and Bridge Replacements

It is estimated that more than 1/3 of the over 600,000 bridges in North America are in urgent need of repair. This situation is especially acute at county or municipal levels because funds for maintenance and replacement of secondary roadway bridges are limited. The majority of bridges on the secondary system are termed short span, less than 15 m in length, and can be replaced or rebuilt with corrugated steel structures; conventional corrugated steel pipe and pipe-arches, structural plate pipe, pipe-arches, arches, steel box culverts, or long span culverts.



Long span structure under construction for grade separation.

LONG SPAN STRUCTURES

In the late 1960's, developments were made which involved adding longitudinal and circumferential stiffening members to the conventional 152 x 51 mm corrugation structural plate structures which permitted the use of larger sizes and increased permissible live and dead loads.

This concept made it possible to achieve clear spans up to 18 m and clear areas up to approximately 100 m². With the introduction in Canada of 381 x 140 mm deep corrugated structural plate in the 1990's, clear spans increased to 23 m with clear areas of 157 m². A 400 x 150 mm deep corrugated structural plate product is also available. Long span structures are particularly suited for relatively low, wide-opening requirements. Depth of cover generally ranges from 0.3 to 30 m.

Design procedures covering these long span structures can be found in the Canadian Highway Bridge Design Code (CHBDC) and the latest editions of the AASHTO Standard Specifications for Highway Bridges, Section 12.7, and LRFD Bridge Design Specifications, Section 12.8. These standards provide for the selection of acceptable combinations of plate thickness, minimum cover requirements, plate radius and other design factors.



Backfilling adjacent to long-span structure with structural plate ribs.

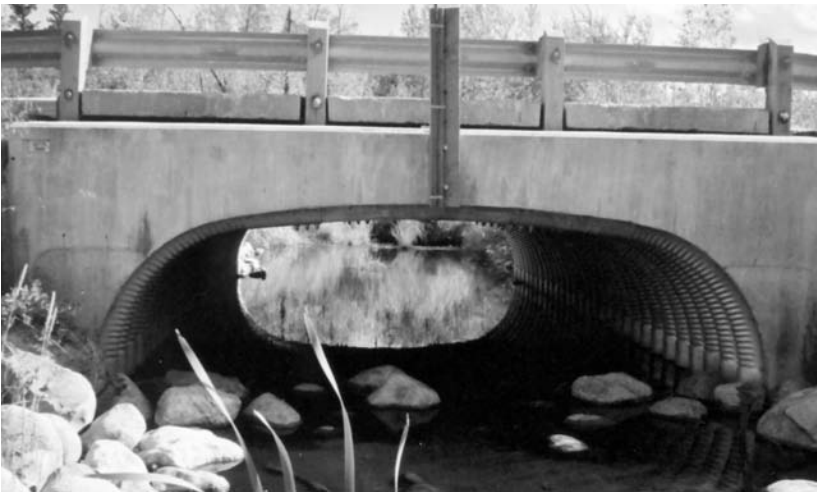
Some of the applications in which these structures are serving include bridges, highway and railroad overpasses, stream enclosures, tunnels, culverts and conveyor conduits. The structures have been extremely popular for bridge replacement, and when used as such provide the following advantages:

1. Eliminates icy bridge deck problems.
2. No bridge deck deterioration problems.
3. Eliminates constant maintenance of bridge approaches and painting of the superstructure.
4. Permits the use of a constant roadway section in the vicinity of the structure.
5. The roadway is easily widened by simply extending the ends.
6. They are readily available and can be field assembled with unskilled labor.
7. Less design and construction time is required, allowing earlier project completion.
8. Environmentally preferred since they permit the natural appearance of earth slope and vegetation to be utilized.
9. Economical.

For available shape configurations, sizes and waterway areas, consult Chapter Two, Product Details and Fabrication. If an appropriate structure to meet project requirements is not shown, a design to meet specific site conditions can be provided by the manufacturers.

CORRUGATED STEEL BOX CULVERTS

Many roads were built along the path of least resistance for early travelers, and this meant easy access for fording streams. As roadways and modes of transportation improved, bridges were built to avoid fording streams. In these locations there is little elevation differential between the desired roadway and the streambed. The shape of the box culvert, with its essentially flat top and vertical sides, is especially well suited for these types of installations where high quantity flows may be encountered, but minimal space is available for deep flows and high backfill covers over the culvert.



Corrugated box culvert bridge.

Box culverts are manufactured from standard 152 x 51 mm corrugated structural plate and 381 x 140 mm deep corrugated structural plate. They can be reinforced with either continuous corrugated plate or intermittent circumferential ribs using corrugated plate or structural shapes.

Standard corrugated box culverts are available in spans up to 8 m with end areas up to 20 m², while deep corrugated box culverts can span up to 12.3 m with end areas up to 36 m².

NOTABLE INSTALLATIONS AND OTHER TYPES OF SEWERS

Although the principal use of corrugated steel pipe (CSP) is for storm drainage, there are some classes of domestic, commercial and industrial effluent which may be handled economically by corrugated steel pipe sewers. The corrosiveness of the effluent is a prime consideration. However, pretreatment of effluents, and a specific required service life may also be pertinent factors. With adequate special coatings, linings and couplings, corrugated steel pipe has, in many instances, given a notable record of economical and satisfactory service.

The Credit Valley Conservation Authority installed over 533 m of 1525 mm diameter CSP for storm control in the Metcalfe Ravine, in the Town of Georgetown, Ontario. Six alternate pipe designs, with full cost estimation and evaluation, were submitted by the consulting engineer. The lowest cost, and recommended alternative, was a design in corrugated steel pipe. The steel estimate was 68% less than the most expensive, and \$16,000 less than the next lowest alternative.

The city of Grande Prairie, Alberta is typical of many modern, fast-growing young urban areas to be found across Canada, all of which are looking carefully at means to make their tax dollars go further. Well over 10 km of steel storm sewers have been installed by the city since 1977, using all-steel drainage design. Owners, contractors, and engineers have realized significant cost savings, whenever corrugated steel pipe is specified, or allowed as an alternate to other pipe products.

A revolutionary new approach to storm water management shows promise to solve, or at least considerably alleviate, the worldwide problem of urban flood damage during major rainfall events. This innovative engineering solution is usually within the taxpayer's pocketbook. Temporary detention of stormwater in underground storage tanks has been demonstrated as cost-effective in a prototype installation in a section of the then Borough of York, in northwest Metro Toronto. Basement flooding in the area previously occurred on an average of once a year. Since completion of the flood relief works in October 1978, there has been no basement flooding despite some major storms. The new works were designed to provide protection against up to ten year storm events. Preliminary estimates to provide overall storm relief and sewer separation for the Borough, based on a 1968 engineering study plus inflation, would have required expenditures over 25 years in excess of \$40 million. From 1968 to 1976 approximately \$6 million had been spent for separating storm and combined flows, and the three most extremely susceptible problem areas still required relief construction. The overall cost of the completed relief works for these three areas was approximately \$988,000, or roughly one year of the Borough's budget to solve the flooding problem.

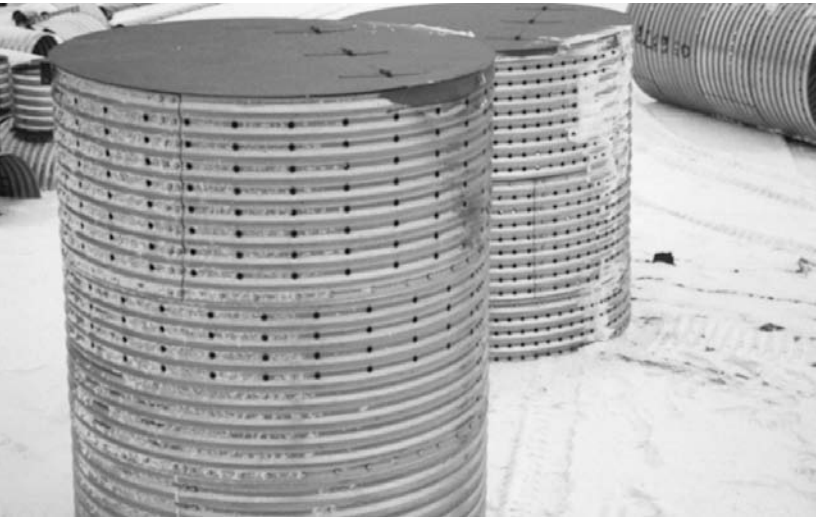
STORM WATER MANAGEMENT

The continuing spread of urbanization requires new drainage concepts to provide efficient and safe disposal of storm water runoff. Existing storm drains in most areas

cannot handle the additional volume at peak flow times. Severe flood damage can occur without storm water management utilizing such tools as retention and detention systems.

Retention Systems

Where storm water runoff has no outlet for disposal, a retention system is a viable solution. The storm water is deliberately collected and stored, then allowed to dissipate by infiltration into the ground. Additional benefits are the enhancement of the ground water resources and the filtration of storm water through percolation. The use of fully perforated corrugated steel pipe for recharge wells and linear pipes is a very cost effective way of disposing of excess storm water.



Perforated pipe for storm water management pond discharge treatment and quality control.



Perforated CSP riser surrounded by clear stone for storm water quality treatment and discharge quality control.

Detention Systems

Where storm water runoff has an outlet that is restricted due to downstream use during peak flow periods, a detention system can be used. Temporary detention of storm water in corrugated steel pipe storage tanks can be most economical and reliable.

Storm water is detained beyond the peak flow period and then systematically released into the downstream storm drain. The demand for zero increase in rate of runoff is very apparent in urban drainage design. Using corrugated steel pipe for detention and retention systems answers that need.

For further details of storm water management covering retention/detention and surface disposal, please refer to CSPI publication, "Design of Underground Detention Systems for Stormwater Management".



Stormwater detention system.

Subdrainage

Subdrainage is the control of ground water, in contrast to surface water or storm drainage.

Subdrainage is a practical, economic way of maintaining firm, stable subgrades and structure foundations, eliminating wet cuts and preventing frost heave, preventing sloughing of fill and cut slopes, keeping recreational areas dry, and reducing saturation of backfill behind retaining walls.

The civil engineer considers soil as an engineering construction material for road and building foundations, backfills for retaining walls, embankments, and cut sections for roads, highways and channels. The engineer is concerned about the basic soil characteristics, the presence of ground water, and whether subdrainage is practical for the soils on the project.

With a little study and experience, many soil and ground water problems can be recognized and solved with subdrainage pipe. For the more difficult cases, a soils engineer and soil testing laboratory are indispensable.

SPECIAL WATER RELATED ISSUES

Erosion Prevention

Soil erosion by water is a common and destructive force that plagues many engineering works. It makes unsightly gullies on roadways, cut slopes and embankments. It gouges out side ditches, fills culverts with sediment and is a costly nuisance.

There are three basic ways of preventing erosion. The first is to treat the surface by paving, riprap, erosion-resistant turf, vines, or other vegetation. The second is to reduce the velocity of the water by means of ditch checks. The third is to intercept the water by means of inlets and convey it in corrugated steel flumes, pipe spillways, stream enclosures, or storm drains. Larger streams may be controlled by steel sheeting, jetties, or retaining walls.

Corrugated steel pipe, with its long lengths, positive joints and flexibility to conform to shifting soil, provides a most dependable means of solving erosion problems.

Dams and Levees

Earth dams, levees and many other types of embankments require culverts or outlets for intercepted or impounded water. Corrugated steel pipes are particularly advantageous and have enviable records for this type of service

Small dams are used extensively for soil conservation and to supply drinking water for livestock. Large dams may impound water for public supplies, irrigation, power, recreation, or navigation. All dams require some means, such as a drain pipe spillway, to handle normal overflow and prevent overtopping and possible washout. For emergency overflow, a turf covered ditch, or one lined with a corrugated steel flume, or chute is usually satisfactory.

Soil conditions at these locations are seldom ideal. Hence strong, flexible pipes are needed to resist disjuncting, settlement and infiltration of the surrounding soil. A local or regional office of the Natural Resource Conservation Service (formerly Soil Conservation Service) can be helpful in suggesting suitable details based on proved local practice.

Diaphragms should be located at a minimum distance of 1.2 m from a field joint and, if riveted, midway between circumferential seams.

Drainage Gates

Flap and screw-lift operated water control gates are two types of gates frequently used in combination with corrugated steel pipe products to control water. The latter type is used where extra control is required, but they tend to require timely opening and closing.

Both types are available with round or rectangular openings. Flap gates are available in diameters from 100 to 3000 mm. Slide gates can be specified with nominal slide dimensions from 150 x 150 mm to 3000 x 3000 mm and in diameters from 150 to 3000 mm. Radial and roller gates are also available.

Fish Baffles

In many sites, the need to accommodate migrating fish passage is an important consideration in culvert design.

Transportation and drainage designers should seek early coordination with environmental, fish, and wildlife agencies to ensure that stream crossings that require provisions for fish passage are identified before design commences.

Extensive experience has shown clearly that culverts can be designed to provide for fish passage. Design criteria for the specific fish species should be clarified during project development.

Conversely, prevention of migration of rough fish or lampreys into upstream spawning grounds can also be accommodated, through the incorporation of suitable weirs or barriers into the culvert design.

Several variations in design are possible to accommodate fish passage:

1. **Open-Bottom Culverts** - or arch-type culverts on spread footings retain the use of the natural streambed. This approach is favored in streams with rocky or semi-resistant channels. Selection of a wider-than-usual arch span also provides for maintenance of natural stream velocities during moderate flows.
2. **Tailpond Control Weirs** - have proven to be the most practical approach to meet a minimum water depth requirement in the culvert barrel. A series of shallow weirs, with a notch or small weir for low-flow passage, have proven extremely effective. Larger weirs of more substantial design may require provision for separate fish ladder bypasses.



Structural plate pipe installation with fish baffles attached to invert.

3. **Oversized Culverts** - limiting velocities may require the use of oversized culverts. Oversizing and depressing the culvert invert below the natural stream bed permits gravel and stone deposition, resulting in a nearly natural stream bed within the culvert. Numerous velocity profiles taken during floods indicate that wall and bed friction permit fish passage along the wall. In effect, the roughness of the steel barrel assists in fish passage.
4. **Culverts with baffles** attached to the invert - considerable recent laboratory and prototype research has indicated that baffles or spoilers can significantly aid fish passage.
5. **Multiple barrel installations** - have proven particularly effective in wide, shallow streams. One barrel can be specifically designed with weir plates inside the barrel to provide for fish passage. The use of baffles in the barrel

of a drainage structure is also useful at sites where energy dissipation may be desirable.

Power Plant Cooling Water Lines

Power plants require vast amounts of cooling water. Structural plate steel pipes over 6 m in diameter have been used for water intakes. These lines are typically subaqueous, requiring special underwater construction by divers. Corrugated steel is especially suitable for this type of construction and has been used for such lines in the Great Lakes region.

Thermal pollution is a major problem with discharge water from power plants. In large deep bodies of water, long discharge lines of structural plate pipe can carry the heated effluent to sufficient depth for dilution or tempering. In shallower waters a unique approach is to use multiple lines of perforated structural plate pipe. Ontario Hydro has used the latter design at the Darlington generating plant in Ontario.

Sheet Flow Drainage

Intercepting sheet flow drainage at highway intersections, driveways and at the elevated shoulder of curves, has become a critical element in highway design. For example, snow pushed to the high-side shoulder on a curve melts as sunlight heats the pavement and shoulder. The runoff from the snow flows back across the roadway and freezes as evening temperatures fall. The result is sheet ice in a very critical area, creating a dangerous traffic hazard and repetitive maintenance problem.

The solution is a continuous longitudinal slotted corrugated steel pipe installed at the junction point between shoulder and roadway. This narrow slot intercepts runoff before it crosses the roadway area.

The system provides an inlet, runoff pipe, and grate all in one installation, and it can be perforated to double as a subdrain.

MISCELLANEOUS APPLICATIONS

Steel conduits serve many practical purposes other than for drainage and sewers. Some of these are:

Underpasses or tunnels for safe movement of people, animals and vehicles.

Materials handling in conveyor tunnels, aerial conduits or systems protected by conveyor covers; and storage bins for aggregates and other materials.

Utility conduits for protecting pipe lines and cables; also entries, escapeways, ventilation overcasts and air ducts.

Underpasses for Pedestrians and Animals

Pedestrian underpasses find their principal use in protecting people who would otherwise be forced to cross dangerous railway tracks, streets, or highways.

Safety is not the only advantage. Where a business, industry, or institution is divided by a busy street or railroad, a structural plate underpass is often the most convenient, economical and direct means of access.

Frequently, large farms and ranches are divided by a highway or railroad, requiring livestock to make repeated dangerous crossings. These barriers are also dangerous for animals in the wild. An underpass under the road is often the most satisfactory solution to this problem.



Snowmobile underpass.

Vehicular Underpasses

Large underpasses serve as grade separations for automotive and railway traffic. For example, a county or local road can be carried under a primary highway or railroad, often at less cost than building a bridge.

Material Handling Conveyors, Tunnels and Granaries

When a plant property is divided by a roadway or other barrier, a tunnel, or an aerial bridging conduit may serve to economically join the property. In some cases a conveyor cover for short or long distances can serve to protect the products from the elements while en route. Tracks, conveyor belts, or walkways may be used in these tunnels, bridging conduits, and conveyor covers. Conveyor tunnels of heavy wall thickness corrugated steel pipe are commonly used under storage piles of aggregates and other materials.

Storage bins of heavy curved corrugated steel plates are used on construction projects as well as in plant material yards.

Utility Conduits

Water, steam and gas lines, sewers, or power cables must often pass between buildings or beneath embankments or other surface obstacles. Good engineering practice calls for placing them within a conduit to protect against direct loading, impact, corrosion, temperature extremes, and against sabotage or vandalism.

For encasing sewers or high pressure lines, a corrugated steel conduit helps minimize damage to the fill and surface installations caused by sudden breaks. A conduit large enough to walk through provides better access for inspections and repairs. Brackets and supports are easily installed in pipes.

Utility conduits or tunnels may also double as air ducts. In the case of mines, munitions plants and other hazardous activities, these conduits may serve as ventilation overcasts and escapeways. See Aerial Conduits.



Corrugated pipe provides excellent conduit for utility lines.

Bent Protection Systems

In cases where surcharge piles from conveyors press against conveyor bent supports, corrugated steel structural plate may be used to reinforce and protect the bents.

AERIAL CONDUITS

Introduction

Aerial conduits include at least two classes of structures. The first is exposed sewers, gravity water lines and service tunnels or bridges. The second class includes ducts for air and various gases for ventilation or circulation. Aerial access bridges for safe movement of personnel or intra-plant materials handling also are described here.

Sewers and Water Lines

Often the need arises to establish a satisfactory gradient above ground for sanitary outfall sewers, irrigation or gravity water lines that cross depressions, streams, or channels. These exposed lines may be supported on bents, properly spaced, without need for beams or rails between piers.

Service Tunnels

Aerial conduits can be a good choice in industry rather than ground level crossings or subterranean passageways. Bridging between adjacent buildings of a manufacturing plant may be desirable for more direct access for employees, materials, finished products, or utility lines. Other applications are seen at mine tipples, quarries, or docks where the aerial lines may be quite lengthy.

Ventilation Ducts

Mining, industry and construction operations require various degrees of ventilation to protect against health hazards arising from toxic gases, excessive heat, moisture, dust and possible explosions. Ventilation codes and minimum standards usually are established and policed by provincial agencies. Table 1.1 gives friction coefficients for flow calculations. Corrugated steel pipe and other steel products have been used in ventilating systems for many years.

The use of explosives in tunneling or mining makes resistance to concussion and ease of coupling and uncoupling desirable characteristics of the ventilation pipe. Helically corrugated steel pipe and various forms of smooth wall pipe meet these requirements.



Ventilation ducts.

Table 1.1

Coefficients of friction for galvanized helically corrugated steel pipe for air conduction

Diameter of Pipe, mm	Coefficient of Friction, f^*	Diameter of Pipe, mm	Coefficient of Friction, f^*
150	0.029 - 0.033	300	0.023
200	0.033 - 0.038	400	0.028
250	0.036 - 0.041	450	0.032
		600	0.035

*From Darcy-Weisbach formula: $h_f = f \frac{l}{d} \frac{v^2}{2g}$

where h_f = loss of head under conditions of flow, m
 f = a dimensionless friction coefficient
 l = length of pipe, m
 v = velocity, m/sec
 g = acceleration due to gravity, 9.806 m/sec²
 d = internal diameter of pipe, m

Fan Ducts

Mine ventilation conduits or fan ducts extend from the ventilating fan to the portal of the fresh air tunnel or air shaft. Corrugated steel ducts are widely used due to their high strength-to-weight ratio. Further, they are fully salvageable if a change of operations is necessary. They resist destruction from explosions, are fire resistant, and contribute to mine safety through confining explosion and fire in event of disaster. Corrugated steel ducts may range from 900 to 2200 mm diameter, with 1200, 1600 and 1800 mm being the most common sizes.

Normally, the duct is fabricated so that the fan opening is offset from the centerline of the main conduit to prevent damage to the fan in case of explosion. Spring-loaded explosion doors installed on the outlet end of the main duct serve to relieve pressures and minimize damage to ventilating equipment.

Air lock chambers can be installed on the side of the main conduit for entry into the air tunnel if desired.

Heat Manifolds and Stacks

Concrete aggregates must, at times, be heated or cooled prior to mixing in order to obtain satisfactory working and setting properties of the concrete. Corrugated steel pipe inserted through aggregate piles have been commonly used as heat conduits. Heat transfer through pipe walls is rapid. Also, ample structural strength and complete salvageability are advantageous.

Corrugated steel pipe is used for heat manifolds, ducts and stacks for smoke and fumes. Galvanized steel is satisfactory except where the fumes are corrosive, in which case protective coatings can be specified.

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