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DEVELOPMENTS IN THE USE OF HIGH ALLOY STAINLESS STEELS FOR OFFSHORE FIREWATER SYSTEMS

"NOT JUST A PIPE DREAM"

The authors are Dr. C. V. Roscoe, Dr. K. J. Gradwell and Mr. M. R. Watts of Mather & Platt Machinery Ltd, Manchester, ENGLAND

and

Mr. R. A. Whiteley, Wormald Engineering Ltd, Manchester, ENGLAND

SUMMARY

Offshore firewater systems have traditionally been in carbon steels and more recently in 90/10 cupro-nickel alloys. These materials have severe limitations which present difficulties to both the Design Engineers and Operators. The development of super-duplex and super-austenitic stainless steels has resulted in materials which overcome the inherent system problems that occurred with the traditional materials. The utilization of stainless steels in firewater systems in preference to cupro-nickel alloys can also give substantial reductions in pipe sizes, weight and cost. This paper examines past practices and briefly reviews the 'state of the art' development in utilizing stainless steels for firewater systems. A case study is presented to show the advantages of using super-duplex stainless steel in a typical firewater system.

HISTORICAL PERSPECTIVE

The first generation of North Sea Platforms relied upon American offshore experience and land based technology. Firewater systems used carbon steel pipe either lined, for ring main service, or galvanised for sprinkler and deluge systems. The use of carbon steel pipe, whether lined or galvanised, has given firewater systems a reputation for unreliability once in service. The principal operational problem has been associated with blocked nozzles resulting from the detachment of anti-corrosion coatings or from sediment (corrosion products) in the water. Although system design techniques exist to minimize the effects of sediment build-up, commercial restrictions have generally prevented their full implementation. However, the field service problems of scaling and lining detachment have not been overcome and these are particularly insidious in highly corrosive marine environments.

In view of these problems the second generation of North Sea platforms have utilized 90/10 cupro-nickel pipes for the firewater systems. While 90/10 cupro-nickel shows fairly good resistance to sea water corrosion its use in firewater systems is limited by the velocity constraints of the material. Owing to the poor mechanical properties and erosion performance of the 90/10 cupro-nickel material, systems are designed using velocities between 1- 3.5 m/sec for continuously flowing firewater ring mains and up to 7m/sec for downstream deluge pipework. The fluid velocity restriction has meant that pipe sizes and total system operating weights have increased markedly over those for steel systems. The resultant low operating velocities has led to many orifice plates being required in the systems since there is not enough hydraulic loss in the system to absorb the available water pressure.

There is also the problem of galvanic compatibility between the cupro-nickel pipe and the carbon steel supports which require special installation kits to avoid corrosion. These supports are typically placed 2 metres apart in view of the poor rigidity (low Young's modulus) of the cupro-nickel pipework. There are further difficulties in using cupro-nickel alloys associated with their vulnerability to damage during handling. Furthermore, in view of their poor fabricability, welding times for cupro-nickel alloys are often greater which leads to higher "knock on costs" in the fabrication yards. These problems

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are magnified when retrofit work has to be carried out to firewater systems on offshore platforms.

CURRENT DEVELOPMENTS

The two categories of stainless steels which are most frequently under consideration when the fluid medium is sea water are the highly alloyed 6Mo austenitic stainless steels, and the super-duplex ferritic-austenitic stainless steels. Table 1 shows a list of some typical commercially available grades. The super-duplex stainless steels offer several advantages when compared to the highly alloyed austenitic stainless steels and/or 90/10 cupro-nickel alloys and some of these are listed below:

1. The proof strengths of the super-duplex stainless steels are approximately twice those of 6Mo austenitic types and more than 4 times those of 90/10 cupro-nickel alloys.

2. Tensile strengths are approximately 30% higher than that of 6Mo austenitic types and more than twice those of 90/10 cupro-nickel alloys.

3. Localised corrosion resistance is equivalent to or better than the 6Mo austenitic stainless steels in seawater. This is particularly important in systems where there is a likelihood of environments containing chlorides and H_2S. In H_2S containing environments 90/10 cupro-nickel alloys are extremely susceptible to corrosion.

4. Vastly superior weldability.

5. Corrosion-erosion resistance is generallly better than 6Mo austenitic stainless steels and 90/10 cupro-nickel alloys; the latter of which has a velocity constraint of 3.5m/sec under continuous flowing service.

6. Material and fabrication costs are lower than the 6Mo austenitic stainless steels and 90/10 cupro-nickel alloys especially when account is taken of the superior mechanical properties.

Although many parameters determine the suitability of a stainless steel for applications in firewater systems, in most oil and gas field duties the localised corrosion is the key parameter. One method available to the pipework designer of evaluating the pitting and crevice corrosion resistance of these highly alloyed stainless steels is to examine their relative PRE_N values (Pitting Resistance Equivalent). The general formula for nitrogen-containing super-duplex and austenitic stainless steels is as follows [1],

$$PRE_N = \% Cr + 3.3\% Mo + 16\% N_2$$

It is generally regarded that PRE_Nvalues of greater than 40 are necessary to guarantee the localised corrosion resistance of a stainless steel in oxygenated sea water and both the super-duplex and 6Mo austenitic stainless steels satisfy this criterion.

While there are reservations concerning the utilization of such formulae in total isolation, incorporating minimum PRE_N values into specifications enables a more consistent corrosion performance to be obtained

To demonstrate the important influence of PRE_N value on the localised corrosion performance of stainless steels a number of accelerated corrosion tests have been undertaken in seawater using potentiostatic polarization techniques.[2] Figure 1 shows a graph of the critical pitting temperatures obtained for a variety of stainless steels with different PRE_N values. From these results the alloys can be ranked in terms of their critical pitting temperature in seawater as follows:

most resistant	ZERON 100
	6Mo austenitic (UNS S31254)
	ZERON 25 and Sanicro 28
	2RK65, SAF 2205 and Ferralium
least resistant	316L.

A similar correlation has been shown to exist if the critical crevicetemperatures determined for these alloysare plotted against their respective PRE_N values [3].

The crevice corrosion resistance of stainless steels and nickel alloys can also be determined using a mathematical modelling technique which simulates the corrosion process [4]. The technique takes account of many factors including crevice type, crevice geometry, crevice solution, alloy composition, bulk solution etc. An example of the ranking produced by this technique is shown in Figure 2[5]. From these results it can be seen that both the super-duplex (ZERON 100) and the 6Mo austenitic (UNS S31254) stainless steels give excellent resistance to crevice corrosion.

Although not represented on Figure 2 the conventional lower alloyed duplex stainless steels such as 2205 or Ferralium generally give a crevice corrosion performance which varies in the region of 500-700 on the ranking scale depending upon the PRE_N value of the material.

The ranking shown in figure 2 has been quantified in terms of crevice gap since after the level of alloying this is one of the most important parameters in determining whether or not crevice corrosion will occur. The data in figure 2 can be used to define a critical gap for each alloy below which crevice corrosion will occur. Previous studies have reported that minimum gaps in the range 0.2- 0.5 um are typical in practice, while gaps of less than 0.2 um are extremely unlikely[6]. This means that Inconel 625, ZERON 100 or UNS S31254 are acceptable materials for aerated seawater applications, whereas UNS S8904, conventional duplex stainless steels, type 316, type 304 or the 430 stainless steels are not.

Experience has shown that the 6Mo austenitic stainless steels can be extremely difficult to weld satisfactorily and can suffer from hot cracking if interpass temperatures are not controlled to 150°C maximum, particularly in respect of cast flanges, valves, pumps etc., which generally exhibit very coarse grain sizes [7]. If it is not possible to carry out a post weld heat treatment operation, then overalloyed nickel base alloy consumables containing 9 wt% of molybdenum (E Ni Cr Mo-3) have to be utilized to ensure that the localised corrosion performance and mechanical properties of the weld metal and HAZ are not too significantly inferior to that of the parent metal.

However, it should be emphasized that minor amounts of second phase intermetallics, carbides and nitride phases have been reported to precipitate in the interdendritic regions of highly alloyed austenitic structures [8]. These precipitates will inevitably reduce the mechanical properties and corrosive performance of weldments. Furthermore niobium-rich precipitates have also been observed in the over alloyed weld metal, which typically contains niobium in the range 1wt% to 4wt%. The niobium-rich precipitates have resulted in micro cracking in the weld metal adjacent to the fusion boundary.

Future developments in the composition of the overalloyed welding consumables utilized for the 6Mo austenitic stainless steels will therefore include reducing the niobium content to less than 0.5 wt%. This aims to eliminate the micro cracking problems now being experienced.

In respect of the super-duplex stainless steels it is also necessary to control the welding parameters to achieve optimum mechanical and corrosion resistance properties. However, if the welding operation is properly controlled the duplex weldment possesses toughness and corrosion resistance from the presence of the austenite phase whilst the ferrite will impart strength and resistance to SCC. Combining the austenite and ferrite phases in a duplex structure improves weldability above that of single phase stainless steels. The austenite, having a higher solubility for hydrogen, acts as a 'sink' thus reducing the likelihood of cracking in the heat affected zone at low temperatures and the presence of ferrite reduces any tendency for hot cracking of weld metal.

Duplex stainless steels are also more resistant to weld decay than austenitic stainless steels, since the chromium depleted zone, which occurs if $M_{23}C_6$ were to precipitate, is extremely narrow. This zone is quickly replenished with chromium by diffusion from the interior of the austenite grains and this results in rapid healing of the sensitized microstructure. Indeed, since the maximum carbon content permissible in the super-duplex stainless steel ZERON 100 is 0.03 wt% the resistance to sensitization is even greater owing to the low propensity of $M_{23}C_6$ precipitation.

Welding consumables used for super duplex stainless steels ensure that the volume fractions of ferrite and austenite are the same in the weld metal as in parent material, and excellent weld metal toughness is achieved. These consumables are also manufactured with PRE_N values of 40 minimum to ensure that the localised corrosion performance of the weld metal is not inferior to the parent material. A series of localised corrosion tests have been carried out on ZERON 100 weldments using 10% $FeCl_3$ solution in accordance with ASTM G48 Method A. These tests (Table 2) have shown that the pitting and crevice corrosion resistance of the weld metal, HAZ and parent material is superior to that observed for the 6Mo austenitic stainless steels..

Relative to cupro-nickel or 6% Mo systems it is possible to reduce the wall thickness of pipes in super-duplex stainless steels in view of the high strength properties. This in turn leads to faster welding speeds whether using a manual and/or automatic welding techniques.

It is likely that the corrosion erosion resistance of the super-duplex stainless steels is better than the 6Mo austenitic stainless steels in view of the material's higher hardness property, especially since there is little difference in the corrosion performance of these two materials. Indeed super-duplex stainless steels have been used successfully in seawater systems with velocities up to 90m/sec at the tips of pump impellers. In super-duplex stainless steel water systems the velocity of the system is limited by the hydraulic design to typically 12-15m/sec. This can be contrasted with cupro-nickel firewater systems where the material limits the velocity of the system to 3.5 M/Sec. Therefore the nominal diameters of the pipes in super-duplex stainless steel can be reduced relative to pipework in cupro-nickel alloys.

The inherently greater mechanical properties of super-duplex stainless steel also makes for easier handling and fewer pipe supports than are currently needed for cupro-nickel firewater systems. This not only offers savings in fabrication and construction but also reduces the weight of the firewater systems thus reducing the overall weight and cost of the platforms.

FIREWATER SYSTEM- A CASE STUDY

In order to evaluate the potential benefits of using pipework in stainless steels in preference to 90/10 cupro-nickel, a typical deluge system has been sized using a computer hydraulic programme (Fig 3). The system had to meet the minimum nozzle pressure and flow required, and had 10 bar inlet pressure available from the ringmain.

The programme utilized 6m/s velocity limit in cupro-nickel and 10 m/s in super-duplex stainless steel. Although the super-duplex stainless steel is capable of much greater velocities the Renolds number of water changes at higher velocities and requires a revised calculation procedure. The results are shown in Table 3a.

From this study it is possible to deduce the following:

1. Due to velocity limitations with cupro-nickel, the system is unable to utilize the available inlet pressure. As a result it would be necessary to install an orifice plate to create a 4.72 bar pressure drop at the deluge valve set.

2. The super-duplex stainless steel system has smaller pipes and as a consequence a smaller deluge valve set would be required.

3. As a result of the smaller bore stainless steel system, the dry weight is reduced by 15% compared to cupro-nickel and the wet weight by 33%.

4. The increased strength of stainless steel enables 38% fewer pipe supports to be used and eliminates the need for the comprehensive insulation kits.

Typical costs for a stainless steel pipe and fittings package relative to those in a cupro-nickel deluge system are presented in Table 3b. The overall cost of the system is greatly reduced using super-duplex stainless steel in place of 90/10 cupro-nickel.

Support and pre-fabrication costs are much lower for the super-duplex stainless steel. Other savings would also arise from the use of smaller deluge valve sets and skids. The super-duplex stainless steel is also easier to handle, whereas the cupro-nickel is prone to damage.

Extending this analysis to include all the fire water deluge and sprinkler systems (excluding the ring main) for a medium sized platform reveals the information presented in Table 3c. The reduced pipe sizes offer a 10 tonne (20%) reduction in the wet (operating) weight for which the platform must be designed.

Tables 4a- 4c show a similar case study for a typical firewater ringmain. The study has compared pipe call-off quantities using velocity limitations of 3.5 m/sec for cupro-nickel and 7m/sec for stainless steel. A velocity of 10-12m/sec for stainless steel could have been used for this system to parallel to assumptions used in the deluge system example yielding still greater savings in cost and weight. The study reveals the following information.

1. Super-duplex stainless steel pipe is lighter than 90/10 cupro-nickel pipe at the larger diameters due to the reduced wall thickness.

2. Reduced diameter fire water mains can be utilized with super-duplex stainless steel due to their tolerance to higher water velocities. In view of the necessity to supply the helideck on the top of the platform with seawater, there is excess pressure in the ring main for the other duties. Therefore, it is not necessary to specify larger fire pumps when using the additional velocities allowed by stainless steels.

3. Both the dry weight and the wet weight are significantly less when using super-duplex stainless steel. (Table 4b).

Table 4c gives the cost comparisons between 90/10 cupro-nickel and super-duplex stainless steel. These figures show cost savings when using super-duplex stainless steel for:

1. Pipe materials
2. Supports
3. Prefabrication labour

Again the benefits and savings from the easier handling of the stronger super-duplex stainless steel have not been reflected; nor have the benefits from smaller pump delivery and ring main valves.

This study has examined the two major sections of the firewater system, the ring main and the sprinkler/deluge system. The two sections are very different in their design, with the sprinkler/deluge system being made up of many small bore pipes and fittings, and the ring main being mainly long lengths of large diameter pipe. For each of these sections the relative share of the final cost attributable to pipe material, cost of supports and fabrication costs has been detailed. It has to be appreciated that the savings from using super-duplex stainless steel in preference to 90/10 cupro-nickel will arise at different stages in a project.

Operators and engineers need therefore to be aware of all the potential savings when carrying out the decision making process.

CONCLUSION

The offshore industry learning curve on firewater systems has moved from first generation carbon steel to second generation cupro-nickel alloys and seems set to take advantage of the technological developments in stainless steels for the third generation of platforms. High alloy stainless steels are now being used for firewater systems in platforms in the Norwegian Sector of the North Sea. It is clear that recent developments in materials of construction for offshore firewater systems offer the potential for significant cost and weight reduction.

This is particularly true now that oil companies are increasingly taking account of through life costs.

This paper has set out to introduce and explain the developments which are taking place in firewater systems materials technology. These developments will inevitably have a significant impact on future projects.

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TABLE 1

NOMINAL COMPOSITIONS OF COMMERCIALLY AVAILABLE HIGH ALLOYED STAINLESS STEELS

DESIGNATION	PRODUCER	Cr	Ni	Mo	Cu	W	N_2	PRE_N
ZERON 100 *	MATHER & PLATT MACHINERY LTD	25	7.5	3.8	0.7	0.7	0.25	41.5
AL-6XN +	ALLEGHENY	20.8	25	6.5			0.20	45.4
URANUS SB 8!	CREUSOT-LOIRE	25	25	5	1.6		0.15	43.9
254SMO + (UNS S31254)	AVESTA	20	18	6.1	0.7		0.20	43.3
A965 + (UNS S31254)	VEW	20	18	6.1	0.7		0.20	43.3
HR 8N +	SUMITOMO	21	24.5	5.8	0.8		0.2	43.3
AL-6X + (UNS N08366)	ALLEGHENY	20.3	24.5	6.3				41.4
CRONIFER 1925 HMO + (UNS N08925)	VDM	21	25	5.9			0.14	42.7
SANICRO 28 # (UNS N08028)	SANDVIK	27	31	3.5	1.0			38.9
ALLOY NO. 20 MOD # (UNS N08320)	HAYNES	22	26	5				38.8

* Super duplex stainless steel.

\+ 6Mo Super austenitic stainless steel.

\# Highly alloyed austenitic stainless steel.

TABLE 2

LOCALISED CORROSION PERFORMANCE OF ZERON 100 WELDMENTS TESTED IN 10% $FeCl_3$ (ASTM G48)

	CRITICAL CREVICING TEMPERATURE* deg C	CRITICAL PITTING TEMPERATURE deg C
AS WELDED	60-65	70-75
SOL HEAT TREATED	65-70	75-80

* USING MULTIPLE CREVICE WASHERS

TABLE 3a

ALTERNATIVE DESIGNS OF A TYPICAL 40 NOZZLE DELUGE SYSTEM

PIPE DIA	90/10 CUPRO-NICKEL	SUPER-DUPLEX S.S.
1"	36.65m	52.4m
1.5"	23.85m	33.5m
2"	25.4	5.9m
3"	11.5m	28.5m
4"	22.85m	25.0m
6"	25.03m	
Valve Set	150 mm	100 mm
Supports	55	34
Inlet Press Req'd	5.28 Bar	10 Bar
Flow	4368 l/Min	4880 l/min
Pipe Vol	809 l	472 l
Dry Wt	634 kg	542 kg
Wet Wt	1442 kg	960 kg

TABLE 3b

COSTINGS- TYPICAL 40 NOZZLE SYSTEM

	90/10 Cu-Ni	ZERON 100	% CHANGE
PIPING MATL.	6,500	6,400	-2
SUPPORTS	1,100	680	-38
PREFAB LABOUR	7,000	4,000	-43
TOTAL	14,600	11,080	-24

TABLE 3c

SUMMATION FOR TYPICAL PLATFORM DELUGE AND SPRINKLER SYSTEMS

	90/10 CUPRO-NICKEL	SUPER-DUPLEX S.S.
DRY WT	28.5 TONNES	24.3 TONNES
WET WT	46.3 "	36.8 "

TABLE 4a

TYPICAL BILL OF MATERIALS FOR A FIREWATER RING MAIN

PIPE DIA. INCHES	18	12	8	6	4	3	2
CUPRO-NICKEL (3.5m/sec	170	-	5	30	40	-	-
ZERON 100 (7m/sec)		170	-	5	30	40	-
ZERON 100 (12m/sec)			170	-	5	30	40

TABLE 4b

TYPICAL WEIGHTS (Cu/Ni AT 3.5M/SEC, ZERON 100 AT 7M/SEC

	Cu/Ni	ZERON 100
TOTAL DRY WEIGHT (TONNES)	17.4	6.7
TOTAL WET WEIGHT (TONNES)	46	19
PIPE SUPPORTS	123	82

TABLE 4c

TYPICAL COSTINGS OF A FIREWATER RINGMAIN SYSTEM

	90/10 Cu-Ni	SUPER-DUPLEX S.S.	% CHANGE
PIPING MATL.	96,000	60,000	-38
SUPPORTS	3,700	1,650	-55
PREFAB LABOUR	32,010	9,500	-70
TOTAL	131,700	71,150	-46

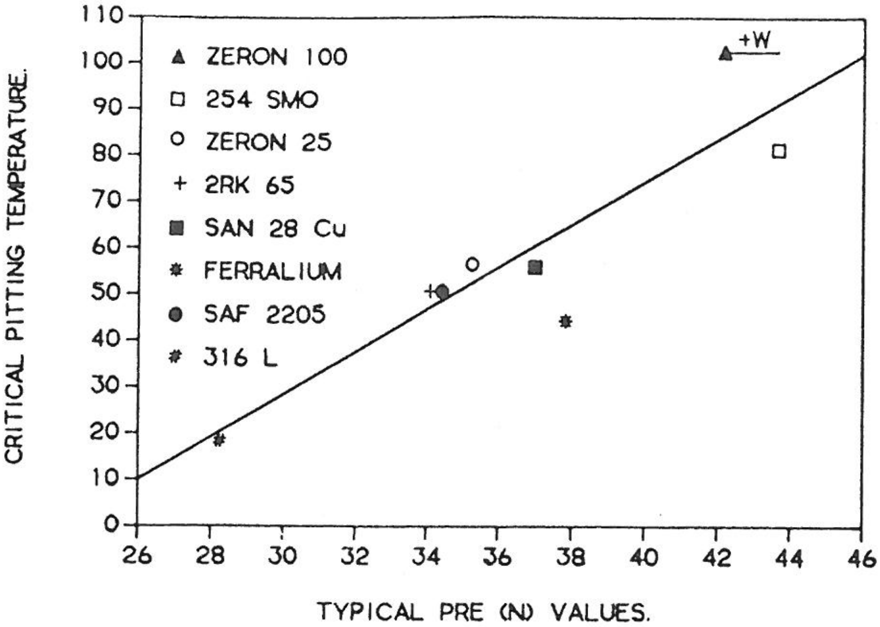

Fig. 1. Graph showing the relationship between the critical pitting temperature and the PREN values for a series of stainless steels

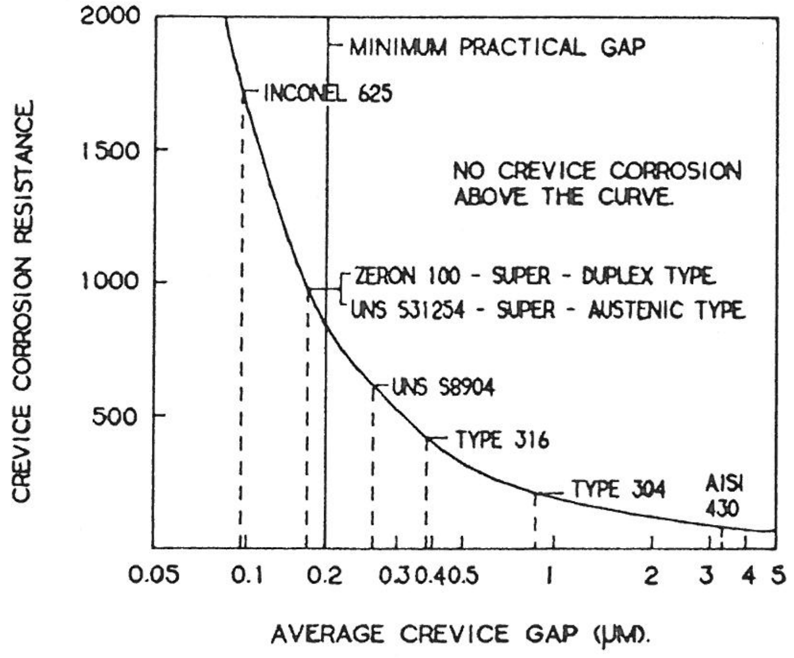

Fig. 2. Prediction of whether or not crevice corrosion will occur in ambient temperature seawater in a 5mm deep crevice of varying widths

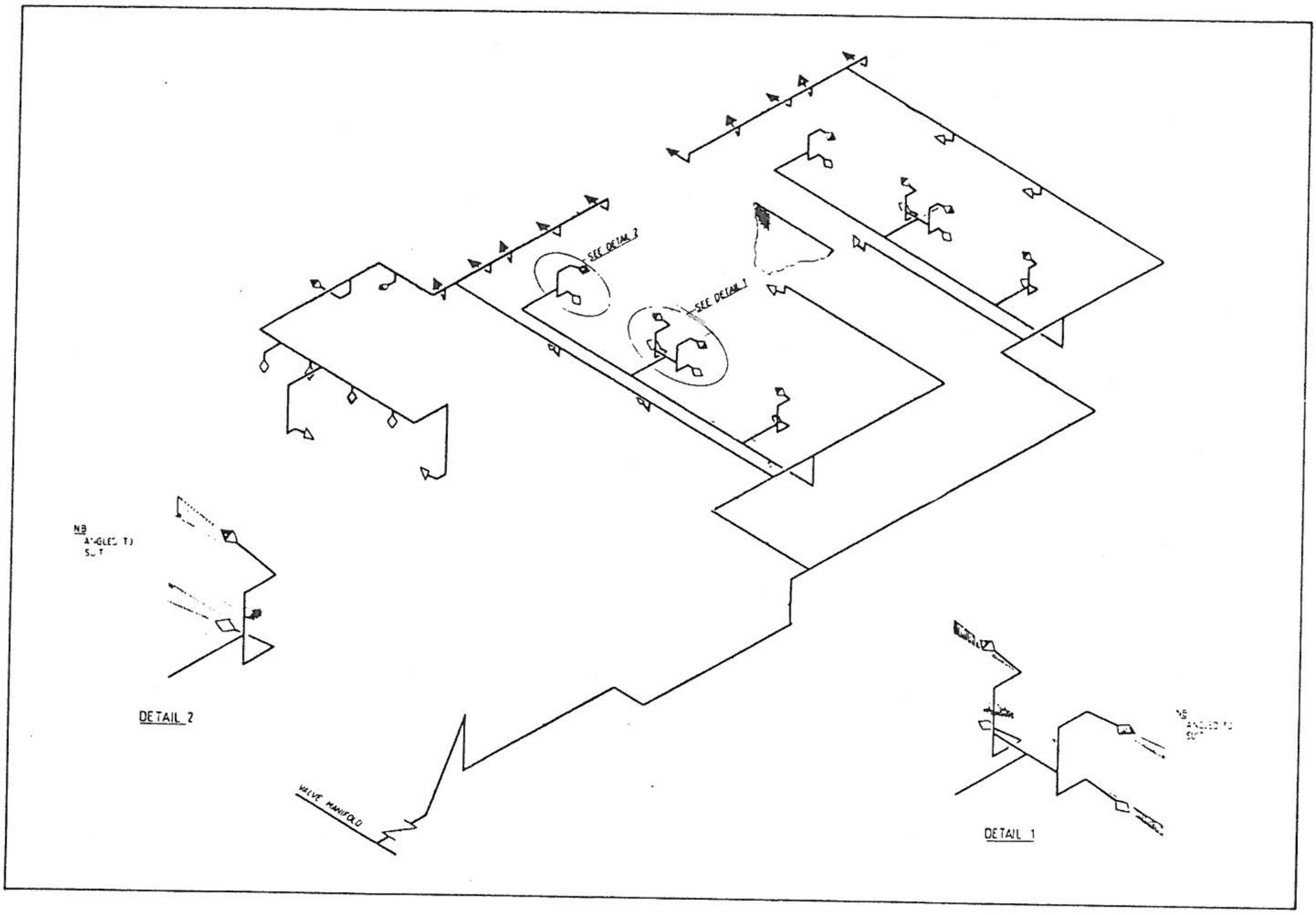

Fig. 3. Typical deluge system

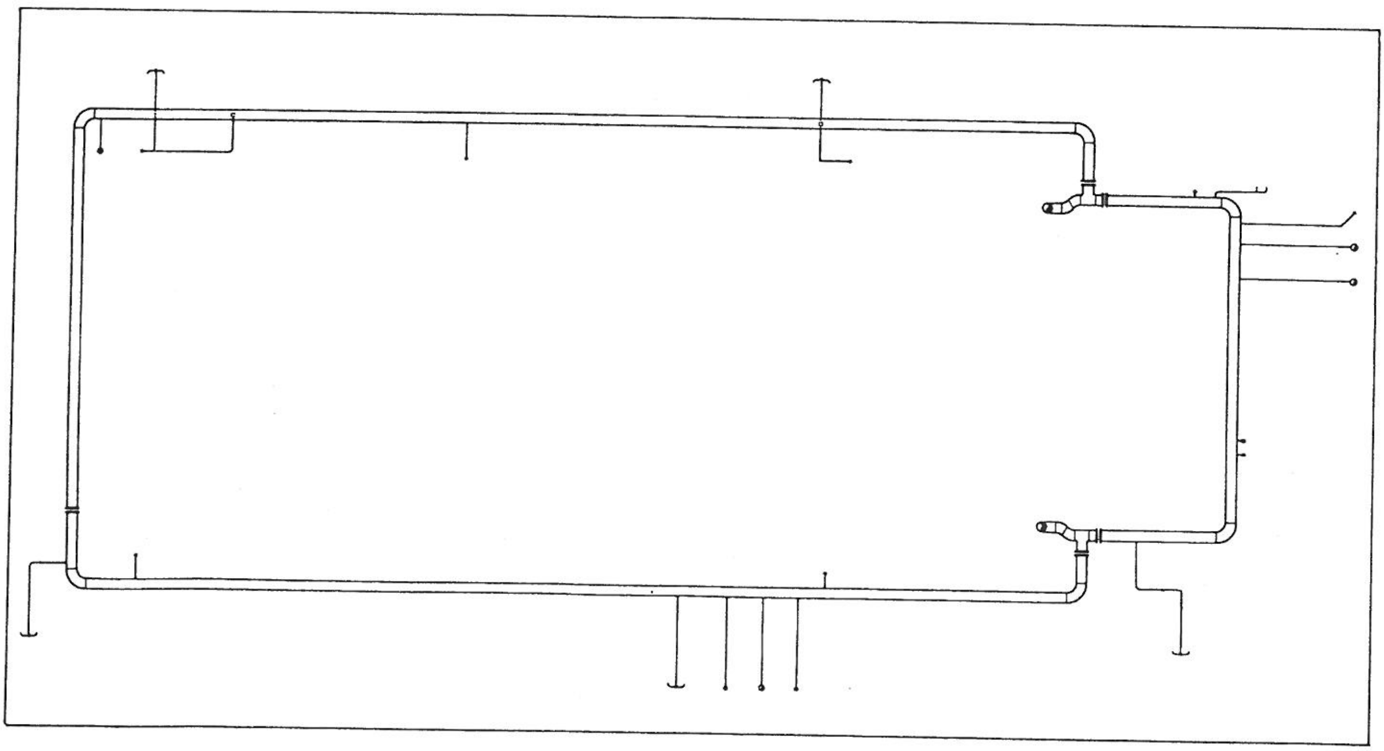

Fig. 4. Typical fire water ring main