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TITLE

DOWNCOMER FOR 105KW AND KE
PROJECT CA-512-R

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Verified By J. E. Savely 4-15-94

DOWNCOMER FOR 105KW & KE

PROJECT CA-512-R

Process Engineering Unit

by T. F. Robinson

& D. Marinos

This document has been reviewed and approved by the appropriate members of Process Engineering. It is approved by the Process Engineering Unit as a basis for 105-K pile design

Distribution

1. 300 file
2. Extra
3. Extra

T. F. Robinson / D. Marinos
Design Engineer

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Group Head

J. R. Walcott
Development Engineer

Worison
Manager, Process Engineering

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TO: FILE

FROM: T. F. Robinson/D. Marinos *92R*

SUBJECT: DOWNCOMER DESIGN - 105-KW and KE REACTOR FACILITIES - PROJECT CA-512-R

Recommendation

1. It is recommended that a cellular orifice screen type downcomer as shown on drawings H-1-22300 and H-1-22362 be provided for the 105-K reactors and similar to Figure 4.
2. It is recommended that one downcomer be provided for each reactor.
3. It is recommended that a single 72" process sewer be provided for each reactor. This process sewer will be supplemented by a 24" by-pass line for carrying shutdown flows during periods of maintenance or inspection of the process sewer. The justification for the single process sewer will be the subject of another report.
4. Although not considered necessary by the Process Engineering Unit, 2-30" relief by-pass lines will be provided.
5. Sufficient spare parts will be provided to replace sections.

Justification

Background

The B & D piles have one cushion chamber type downcomer for each pile. F unit has one downcomer of a cellular type with no orifices. The H, DR, and C piles have two downcomers each of the cascade type. The B, D, and F pile downcomers have not proven satisfactory because the provisions for dissipating the energy are not adequate. (Essentially full impact of the falling water is received in the chamber at the base of the B & D downcomers. The F downcomer dissipate only 15% of the energy in friction in the cells.) Because of the inadequacies in the downcomer designs for these original piles, another design, the cascade type, was hurriedly incorporated into the H and DR designs after some superficial testing. The cascade type does not embody the characteristics of the ideal downcomer, but since no better development was ready at the time C pile was authorized the same basic design was used.

The cascade downcomer reduces the impact loading at the base of the downcomer (as compared to the B & D types) by breaking the free fall at several stages along the vertical height. (See Figure 1) The H downcomer has seven shelves for energy dissipation; C pile has five. The cascade type downcomer has three inherent weaknesses which are sources of concern. First, kinetic energy dissipation is dependent upon the turbulent friction generated by the direct impingement of the water on the various shelves which direct the flow. This causes vibration and resultant fatigue and may result in failure of some of the down-

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comer components. These fractures contribute to both maintenance and safety problems. Secondly, the dimensions of each shelf are such that if they were to break free it could conceivably block the flow. This would, however, require a very special set of conditions (See Figure 1, - Items A & B). Thirdly, maintenance of cascade downcomers is difficult and replacement is extremely difficult. These are encased within the concrete building structure and in order to replace the downcomer, it would have to be cut into pieces for removal. Installation of a replacement would essentially require fabrication in place. Even ordinary maintenance requires working inside the downcomer where space is restricted and surroundings are contaminated. Because of these deficiencies, it was concluded that two downcomers for each pile were appropriate in the design of DR, H, and C piles.

Some time was available for development and improvement for future designs before K pile design was authorized. One of the objectives of this development program was to improve upon downcomer design. It was evident that the proper approach to the problem lay not in duplication because of inadequate facilities as a means of circumventing the resultant effects of failure, but rather in the adoption of a more logical engineering approach --- analyze the cause of failure, profit from the past operating experience, and concentrate upon the removal of these inherent difficulties. Accordingly, a downcomer design embodying a superior method of operation was designed and tested. The design minimizes vibration by dissipation of energy through a series of orifice screens rather than impact loading of large parcels of water and turbulent friction. It greatly simplifies the maintenance problems by designing for essentially complete replacement of the downcomer by ordinary maintenance methods. It provides for very rigid construction of the inlet section and 30 parallel flow paths in the vertical portion and thus the problem of blocking the flow has been eliminated. A more detailed analysis of the points is presented in the following paragraphs.

Safety

As mentioned in the preceding paragraphs, it is possible to conceive a set of circumstances, however unlikely, in which the blocking of a cascade downcomer might occur. Reference to Figures 2 and 3 will show that such is not a possibility with the cellular type downcomer. Construction is such that there are 30 separate and independent water channels. If any of the vertical plates should break loose (and this would require fracturing 16 feet of continuous welds) it could, at the worst, stop the flow in two cells. The effect of flow stoppage in two cells is negligible. In fact, if by some means 50% of the cells should become blocked, the maximum water flow would pass through the remaining half of the cells after developing a 90 psi pressure on the rear face (the rear face piping is designed for 150 psi working pressure). Reference to Figure 2 illustrates the improbability of even one plate breaking loose. Not only is the cellular downcomer rigidly braced from the cell construction (each cell is 7 inches by 16 inches) but the plates are parallel to the flow and the impact of the water does not impinge on them on right angles as it does in the cascade type. In order to minimize corrosion and possible weakening of structural members, the entire assembly will be of stainless steel. (The H and DR downcomers are carbon steel; the C downcomer is stainless steel.)

Welds as shown in Figure 2 will be shop welds made under controlled conditions. The cascade type downcomer has required a substantial amount of field welding of past construction. The quality of field welding, in general, is poorer than

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shop welding.

There is a horizontal approach section which contains straightening vanes for the purpose of smoothing flow. The forces on these vanes are small and do not compare with those on the shelves of the downcomer. Note by reference to Figure 3 that it should require the fracture of 14 continuous welds 72 feet in length before the vanes would be free to sweep downstream. The vanes weigh approximately 4100 lbs. The water velocity through the approach section varies between approximately 14 ft. to 17 ft. per second. Blocking the inlet to the vertical section would require that one of the plates of this configuration be broken loose, broken into the proper size and lodged vertically over the intake. The construction shown in Figure 3 will convince the reader of the impossibility of such a happening. A manhole will be located at the top of the intake section for ready access when inspection is desired.

In summary, the rigid construction, the provision for 30 independent water paths and the minimizing of vibration are all factors which remove the blocking problem from consideration as a problem in this design. Although we believe it unnecessary, two 30" by-pass lines capable of handling the full flow can be provided.

Maintenance

Complete replacement of the entire vertical downcomer assembly can be accomplished in five days; replacement of one of the ten sections will require 12 hours; replacement of any one of the three orifice plates will require three hours each. (These estimates have been confirmed by both engineering and maintenance personnel.) Replacement of a cascade type downcomer would be so difficult that it is not worthy of comparison with the above. A by-pass shutdown line will be provided so that flow may be maintained under shutdown conditions. This line will extend from the 105 Building to the outfall structure. It will be used during periods of maintenance or inspection of the downcomer process sewer.

A second cellular downcomer would cost approximately \$350,000 per pile. Justification for a second downcomer would require an assured saving of at least 14 days of operating time if the value of each day's operation is \$25,000. (This value is based on current accounting processes and was obtained by personal communication with W. M. Harty.) Even two complete downcomer replacements would not justify the addition of a second downcomer. Moreover, it is quite likely that if the downcomer were replaced the operation would be scheduled during a planned maintenance period and the full five days would not be chargeable to downcomer maintenance. Extended shutdowns have occurred in the past, are scheduled for the future, and will be required beyond this. There will be many improvements in the future which will indicate the desirability of modifying the K piles. The fact that this downcomer is new does not argue for duplication. If it should develop that there are problems, it is logical that these should be corrected in the replacement installation.

In summary, economic considerations do not justify placing an investment in a second downcomer. If it were provided it may never be used. Even if replacement is required the time required for replacement does not indicate a second downcomer is justified. There is no reason to believe that if a failure develops that it will be an abrupt failure. In fact, experience in the past has shown that downcomer failures are progressive failures and that maintenance can be planned and scheduled. (Note: Installation of two cellular downcomers would require elimination of the tool dolly room.)

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Performance

The cellular downcomer has been tested at the Washington State College testing laboratory. Although the final technical report has not been issued, frequent exchanges of data, and observations of testing are sufficient to confirm the adequacy of the design. A complete report of the technical aspects of the downcomer as obtained by testing will be issued in late December.

Model dimensions of the tested assembly were one-fifth full scale dimensions. In order to reduce flow requirements, only one of the parallel sections was constructed so that it could be tested with 1/15th of the design flow. Since these parallel sections are essentially identical across the width of the downcomer, reduction of size in this manner does not affect the model scaling. Test results were very satisfactory. Measured flows were within 3% of the calculations and there was no vibration.

Design of a cascade downcomer for K pile would require scaling up H pile experience by a factor of three. The calculations are more difficult for the cascade downcomer. The plates deflecting the flow must be larger and the impact forces three to four times those of the H downcomer. Design of a new cascade would not be a simple extrapolation of known data. In fact, based upon the test results of the cellular downcomer, it is known that design of the cellular downcomer for these increased flows can be undertaken with greater insurance of operation than with the cascade type.

Cost

The following would be the cost increases for various alternate designs.

1. Single cellular downcomer, two 30" by-pass lines, one 24" shutdown line to outfall lines and <u>one</u> 72" process sewer	\$	.00
		(Reference point)
* 2. Double cellular downcomer, <u>two</u> 72" process sewers	\$	1,000,000.
* 3. Double cascade downcomer, <u>two</u> 72" process sewers	\$	900,000.

(Note: If one process sewer were provided, the cost increase for cases 2 and 3 would be reduced to \$700,000 and \$600,000 respectively.)

- * Includes an allowance for spare parts for the single downcomer installations. If spare parts were not provided, the cost differences would increase by \$125,000.

The above figures include the effect of the process sewer because the selection of one versus two sewers is closely allied with the problem of one versus two downcomers. Although it is not the purpose of this discussion to present the justification for a single process sewer, it is worth mentioning that it is being recommended by Process Engineering Unit that a single process sewer per pile be provided.

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SCHEMATIC 105-C DOWNCOMER

Fig. 1

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TYPICAL SECTION THRU DOWNCOMER

105-K

FIG. 2

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NOTES:

1. ALL WELDS ARE CONTINUOUS
2. EXTERNAL STIFFENERS ARE OMITTED FOR SIMPLICITY.

ISOMETRIC SECTION
105-K DOWNCOMER
APPROACH

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SCHEMATIC 105-K DOWNCOMER

Fig. 4

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Amplification:

Indications are that the failures of downcomers in the past have been due to the dynamic forces resulting from the impact of free falling water and/or fatiguing pulsations due to pressure variations caused by unstable flow at high velocities. Excessive free fall in the proposed downcomer has been eliminated. The free fall occurring is confined to only one cell at a time and the orifice plate design has taken this load into consideration. The velocity of the water will be fixed by design at an arbitrary 13.6 ft./sec. Using this same principle of energy dissipation, the velocities in the downcomer could be lowered by merely choosing a larger cross-section area and fitting it with the proper orifice screens. The use of the orifice screens creates sufficient back-pressure to cause the cells to run full and continuous from top to bottom, except for a minor portion that spills into the cell above. The maximum velocities in the approach and discharge to the downcomer are less than that in the downcomer, thus preventing excessive hydraulic jumps and insuring minimum spill-over in the top cell before the bottom cell is full.

Pulsating pressure variations are not expected to be great in magnitude due to the low velocities and smooth flow. The rigidity of the design with the cellular structure and external stiffeners will reduce the vulnerability of the downcomer to pulse variations. Resonance between pulsations and downcomer plates is not expected to be a problem by the same token.

Three orifice screens spaced at 4'-3" intervals at the bottom of the downcomer are expected to wear more than any other portion of the system. The velocities at these plates are still below the threshold of serious wear. All available information points to the life expectancy of these plates in terms of years.⁽³⁾

The entire downcomer will be so designed as to be entirely replaceable. Special attention is being given to the design of the orifice screen assembly. The orifice screen, along with the six inches of cellular section beneath it, are made as a replaceable unit which can be entirely removed and replaced in approximately three hours. These sections are considered the most vulnerable to wear; however, replacement of orifice screens due to wearing is not expected to occur more frequently than once in five years. Furthermore, if such a failure should occur, it would be of a gradual nature so as to be foretold by pressure gages inserted to give the pressure loss across each screen. The exact point of wear at which each plate should be replaced will be highly arbitrary, leaving adequate flexibility in scheduling of maintenance work when required.

The remainder of the downcomer will be made up of flanged sections including the expansion joint section. An overhead traveling crane of sufficient capacity to handle the heaviest of these sections will be permanently installed to be used for initial erection and possible future replacement of any section or even the entire downcomer, should this become necessary. A fixed extension of the elevator tool dolly track opposite the low position of the elevator will be used for transferring

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the parts to and from the building through the tool dolly room. All parts of the downcomer will be accessible to the overhead crane and the elevator tool dolly track extension.

The following is an estimate of time and manpower requirements for various repairs:

<u>Work to be done</u>	<u>*Total Time</u>	<u>Manpower</u>
Remove and replace 1 orifice screen	3 hrs.	6 men
" " " 2 " "	6 hrs.	6 men
" " " 3 " "	9 hrs.	6 men
Remove and replace one downcomer section	12 hrs.	10 men
Remove and replace entire downcomer	5 days	10 men

*This work could not be performed during pile discharging operations due to the elimination of the downcomer shielding wall. (Ref.: Letter H. T. Wells to E. L. Reed, August 14, 1952, Shielding Requirements for Downcomer Maintenance - Bldg. 105-KW)

Type AISI 304 stainless steel will be used throughout for added life with respect to hot water corrosive action. Though the design will include full facilities for the replacement of the entire downcomer or any of its components, it is expected that repairs will be virtually unnecessary.

A one-fifth scale model of this downcomer was built and is being tested at the Hydraulic Laboratory of W.S.C. The tests for major hydraulic characteristics have been completed and minor tests for further refinement are now in progress.

The following information has been obtained thus far from these tests: (5)

1. Orifice screens can be used in a cellular downcomer to dissipate the hydraulic energy of the range of flows desired.
2. Negative pressures will exist below each orifice plate but will not be sufficient to cause cavitation at maximum design temperatures.
3. With the approach section baffled to smooth the mixing of flows from the two risers and to increase the rigidity, satisfactory downcomer operation results for all flow rates.
4. There are no adverse vibration effects to the downcomer or related piping.

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POINT BY POINT COMPARISON OF CELLULAR
ORIFICE TYPE DOWNCOMER WITH
OTHER TYPE DOWNCOMERS

Ideal Downcomer:

The ideal downcomer would be one that formed a path for removal of pile effluent water under all conditions from the top of the rear face to the retention basins or tanks with a minimum of destruction to the path. To do this the ideal downcomer must accomplish the following:

1. Lower water from top of outlet face to retention basins under all flow conditions with a minimum of abrupt interchanges between velocity head and pressure head at any section throughout the path.
2. The velocity head should be low to minimize destructive forces.

1 - Principle of Operation

Cellular Orifice Type

The cellular type downcomer employs full use of guide vanes to direct the flow smoothly throughout its length. The jet impingement occurs only at the orifice screens where the individual jets are very small in comparison to the large mass of water, resulting in minimum destructive forces which lend themselves to analytical calculations. This enables accurate design of the screens to withstand these forces. Free fall is limited to one row of cells at a time and this occurs only until the cell fills when smooth flow is again achieved. Surface tension counteracts turbulence at low flows in the individual cells so that vibration is minimized at all flow conditions. Exit velocities can be calculated and controlled by design. Total energy dissipation can be calculated and controlled by the selection orifice screens as they dissipate approximately 95% of the total energy.

"B", "D", or "F", or "H" & "DR"

- (a) The cushion chambers of "B" & "D" type downcomers receive the full impact of the entire mass of water impinging upon it as a huge jet. The kinetic energy is dissipated in turbulence in the pool of water in the cushion chamber.
- (b) In the "F" type friction losses in the baffles constitute approximately 15% of the total head, leaving the major portion of the energy to manifest itself in high exit velocities. Vanes are employed in the "F" downcomer to direct the water along one side of the pipe leaving the rest of the pipe free for venting. There is a very abrupt change of direction at the downcomer entrance.
- (c) The cascade type downcomer as in H & DR & C dissipate the energy by masses of water impinging first on the cascades and walls at one side, then reverse direction to impinge on the other side before falling to the next cascade to repeat the process. The vertical stream is broken up into a number of horizontal components; the energy being dissipated in turbulence caused by impingement against cascades and side walls. Again, very abrupt changes of direction at the cascades and side walls.

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2- Test Data

Cellular Orifice Type

Analytically calculated data on the cellular type downcomer has been substantiated by tests on a model built to satisfy both Reynold's law and the Froude law of relationship of model to prototype in hydraulic tests. Calculations and tests have agreed within 3%. Tests show that vanes and baffles must be placed so as to smoothly change direction of the flow or else the entire system is adversely disrupted.

"B", "D", or "F" or "H" & "DR"

Operational data show that on all types where there are abrupt changes of direction or regions of great turbulence there is either erosion or fatiguing vibrations set up that have damaged all downcomers that have been in operation for 18 months or greater. The abrupt changes of direction hamper smooth operation.

3- Provisions for Maintenance

Provisions for replacement of orifice screens in an estimated 3 hour time limit have been made. In the event a whole section would require replacement, this could be done in approximately 12 hours time. The entire downcomer could be replaced in 5 days. All of the above provisions have been introduced into the design as a safety plus factor since the tests and calculations show conclusively that this type operates with less turbulence, less destructive jet impingement and lower velocities.

Repair of the cellular orifice screen type is essentially outside of downcomer work in that the sections can be replaced without inside work. This in itself lessens the contamination hazard to persons engaged in working on the downcomer; their exposure to hot vapor drips and etc. is considerably less.

(a) Maintenance of "B" & "D" type downcomers can be done while the unit is down, and repair of cushion chambers has made this necessary. Draining of the chamber is necessary prior to any repair work.

(b) It was estimated that 1 month would be required to reinforce the baffles and entrance elbow in the "F" downcomer (H-1-2065). This repair will allow operation as in the past with the same destructive forces again working against the reinforcement.

(c) In the cascade type maintenance is possible because of twin downcomers, one being in use while the other was repaired. Repairs would consist mainly of reinforcing the baffle shelves, vent lines, and side plates. Only small patch plates and gussets can be brought through limited openings provided to do a repair job.

4- Fabrication (Erection) Methods

Shop fabrication and pre-assembly is possible in 95% of the entire downcomer insuring correct alignment and proper welding of component parts. Erection can take place after the walls have been completed.

Shop fabrication on all other type downcomers is considerably less with all the main structures of the cascade type being field fabricated. Pre-assembly is limited as components are not in small sections. Field welding must be performed.

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5- Probability of Failures

Cellular Orifice Type

Energy dissipation through orifice plates has been tested in other fields and calculated very accurately. Orifice wear tests resulting from the above accuracy demands have brought forth reliable wear data. The reinforcing characteristics of the internal cells add strength to the entire structure to resist damage by dynamic forces. External bracing, adequate to withstand 75 psig pressure is used. This outer bracing without the added support of the cells limits the stress in the outer plate to slightly under 10,000 psi with an internal pressure of 75 psig.

"BR", "DR", or "F" or "H" & "DR"

- (a) Failures of the cushion chambers in previous units and the extent of damage has already been reported as have the cause of these failures. Destructive forces have caused extensive damage to the cushion chamber (SK-1-712). Repairs are now and will continue to be necessary on these units to keep them in operating condition.
- (b) Vanes at the top of "F" downcomer must resist the forces of a horizontal stream of water. Damage to these baffles and bracings necessitates the addition of braces (H-1-2065). The loading on the exit elbow cannot be calculated easily nor can the exit velocities. Without orifice screens to dissipate the energy, the total mass of water would enjoy free fall through-out the downcomer.

All of the above downcomers will require frequent preventive maintenance where changes of direction are not smooth and gradual.

6- Construction Convenience (Effect on the Schedule)

This downcomer would have no effect on the construction of the rest of the unit as it can be erected at any time after the building is nearly complete. The controlling factor in building construction is the rear barricade wall. Constructing the downcomer integral with the wall retards progress on this critical item. The cellular type permits a simplified wall and thus permits an increase in the rate at which building construction can proceed.

(a) & (b) Vane or cushion chamber types have certain components that must be erected during building construction. Portions also can be erected with limited clearance after the building is nearly complete.

(c) Cascade type downcomers are "encased" in the wall structure and must be erected with the walls. The main internal structures and shelves are then lowered from the top and field welded into place. Their construction must be scheduled with the building.

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7- Operation Over a Range of Flows

Cellular Orifice Type

"B", "D", or "F" or "H" & "DR"

Uniform flow conditions have been accomplished for all ranges of flows in the cellular design. Destructive forces are no greater at full flow conditions than they are at any intermediate stage. Since these forces are inherently small at low flows, it follows that smooth efficient operation will result in all ranges.

The forces of a free falling body of water as well as jet impingement forces are proportional to the mass of the water. Thus, as flow increases, turbulence, mass of free fall, and velocity increase, which combine to "overpower" the confining strength of the downcomer.

Cost Estimates - 100-K Downcomer
and Effluent Systems - Project CA-512-R&W

The following cost estimates include labor material and indirect costs on all items. Costs of the downcomer includes the effluent piping to the outside of the 105 building.

CASE I KW & KE

One cellular downcomer per area. This includes two 30 inch bypass lines per downcomer.

plus

One 72 inch line per area from 105 to 107 bldg. diversion box

plus

One 24 inch bypass line per area from 105 riser to 107 building diversion box with one 24 inch gate valve motor operated

plus

Five spare cellular sections. One for each different detail.

Cost installed KW & KE:

	<u>KW & KE</u>
Cellular Downcomers	\$800,000
72 inch line 105 to 107	338,000
24 inch line 105 to 107	67,500
24 inch line / 24 inch M.O. gate valve inside 105	56,750
Encasement for line under R.R. & road	40,500
Total	1,302,750
Round off	1,310,750
Spare Parts	125,000
Total	\$1,435,750

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CASE II KW & KE

Two cellular downcomers per area. This includes one 4 foot by 9 foot rectangular valve with a 42 inch bypass line around it per downcomer

plus

Two 72 inch lines from 105 to 107 building diversion box

plus

Two 72-inch gate valves motor operated

Note: For proper functioning, these downcomers must be separated, one on each side of a unit. Because of this separation, two effluent lines to 107 are used. The case of combining the two downcomers with appropriate valving and using one effluent line to 107 results in as much piping as the case with two effluent lines. The tool dolly room and machine room cannot be provided with this arrangement. Also, the ink system must be relocated.

Cost installed KW & KE:

	<u>KW & KE</u>
Cellular Downcomer	\$1,500,000
72 inch lines with 2 - 72" valves 105 to 107	<u>892,000</u>
Total	2,392,000
Round Off	\$2,400,000

CASE III KW & KE

Two cascade downcomers per area. This includes two 60 inch gate valves motor operated with 42 inch bypass around plus two 60 inch lines out of the 105 building. (These cascade downcomers would be installed side by side with at least a three foot heavy aggregate concrete wall between them and between the downcomers and discharge area.)

plus

Two 72 inch lines from 105 to 107 building diversion box

plus

Two 72 inch gate valves motor operated

Cost installed KW & KE:

	<u>KW & KE</u>
Cascade downcomers	\$1,300,000
3 ft. shielding wall	100,000
72 inch lines & valves 105 to 107	<u>892,000</u>
Total	2,292,000
Round Off	\$2,300,000

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CASE IV KW & KE

Same as Case III except the following is used in place of two 72 inch lines:

One 72 inch line from 105 to 107 building diversion box

plus

Two 72 inch gate valves

plus

One 24 inch bypass line with 24 inch gate valve motor operated

Cost installed KW & KE:

	<u>KW & KE</u>
Cascade downcomers	\$1,300,000
3 ft. Shielding Wall	100,000
72 and 24 inch lines with two 72 inch valves	<u>653,950</u>
Total	2,053,950
Round Off	\$2,060,000

References:

- (1) Letter H. F. Shaw to H. T. Wells, December 3, 1951.
- (2) Letter J. J. Griffiths to J. R. Wolcott, May 15, 1952.
- (3) Letter Bailey Meter Co. to J. J. Griffiths, August 8, 1952.
- (4) Letter H. J. Bellarts to V. D. Nixon, January 23, 1952. (Copy attached)
- (5) W. S. C. Downcomer Test report by J. A. Roberson.
- (6) Letter P. Smith to F. H. Ames/E. L. Reed, August 28, 1950.

Reference Drawings:

- H-1-22300 - 100K Process Water Piping Engineering Flow Sheet
- H-1-22362 - 100K Downcomer Arrangement
- W-73921 - Building 105-F Section Arrangement
- W-77457 - Building 105-F Baffles for 42 inch Outlet Pipe
- H-1-2065 - Building 105-F Downcomer
- H-1-8453DR - Building 105-DR Downcomer Structural Steel Lining and Cascade

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Reference Drawings (Cont'd.):

H-1-8539-DR - Building 105-DR Downcomer Arrangement and Details
HW-70502 - 105-B-D Concrete Foundation Plan
HW-70503 - Building 105-B-D Concrete Ground Floor Plan
HW-71689 - Building 105-B-D Concrete Details Sht. 8
HW-71809 - Building 105-B-D Concrete Details Sht. 9
P-6193 - Building 105-C Downcomer Arrangement & Details
P-1251 - Building 105-H Downcomer Arrangement & Details
P-1252 - Building 105-H Arrangement Downcomer Discharge Piping
P-1258 - Building 105-H Detail - Downcomer Inlet & Discharge

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January 23, 1952

TO: V. D. Nixon
FROM: H. J. Bellarts
SUBJECT: Downcomer Design

1. Background

The Downcomer, also called a Downspout receives process water from the rear of the unit when the water has served its purpose and can be considered a waste product to be disposed of.

Existing downcomers at B & D are large pipes (42" dia.) with free fall of water into a cushion chamber where the energy of fall is dissipated in turbulence. B & D were originally equipped with turning vanes at the top (about 45') level. These vanes have been destroyed in service. The cushion chambers have been severely damaged (and repaired) but are in service.

The "F" downcomer is a similar large pipe, without turning vanes at the top but with a series of baffles about 2" apart so that the water flows in a flat stream instead of the usual round shape. The cells are so arranged that they run full, with their upper end under a slight head and discharging under water at their lower end.

The downcomers at DR, H, C are a "Cascade" type whereby the water is allowed to fall from one large bucket into another at intervals of about 10' apart vertically. Part of the energy is dissipated in turbulence at each level.

None of the previous downcomers is entirely satisfactory.

B & D downcomers have required extensive strengthening, and draw in vast amounts of air which must be vented elsewhere. Cracks have developed in the shells. The cushion chamber underneath is in unknown condition but when last inspected at D in July 1950 it required extensive repairs to the lining (See dwg. SK-1-712).

The "F" downcomer is failing and its replacement is being requested under a Project Proposal. The failure, however, is located at the upper edge of the baffles. These baffles are cracking progressively at the intermittent welds holding them in place and the failure is believed to be due solely to a lack of mechanical strength. For a detailed description of downcomer history, see letter H. P. Shaw to H. T. Wells, dated Dec. 3, 1951, subject "Downcomer repairs in 100 B, DR, D, H and replacement in 100 F".

The Cascade type downcomers are developing cracks at the vent connections. The importance of these cracks is not yet determined.

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2. Design Requirements

The primary engineering problem in downcomer design is how to lower large volumes of hot water a considerable distance without shock, vibration or other destructive phenomena. Further, the equipment should function equally as well with very small volumes of relatively cold water but from the same elevation. All of this equipment must be installed in a restricted space and be adequately shielded.

A satisfactory downspout for RDA-DC 3 therefore must satisfy the following requirements:

1. It must handle 180°F water or 50°F water.
2. It must have ample capacity for 140,000 gpm.
3. It must be adequately shielded.
4. It must be adequately vented.
5. It must be economical to construct and maintain.

The venting requirement is 200 cfm minimum. This is the calculated volume of gases given off by change in solubility due to change in temperature of the water. Air drawn in due to motion of water ("pumping") is indeterminate and is a function of the design of the unit and the flow rate. It is essential that this "pumping" be a minimum.

3. Design Details

It is proposed that the previously stated requirements be met by constructing one rectangular pipe approximately 50" x 70" in cross section. The interior of this pipe will contain a series of cells arranged in a specific and carefully considered pattern, the basic cell being 7" x 16".

At specific waterflows the depth and velocity of water flowing in the cross connection pipe at the top of the downcomer can be calculated. This velocity and depth of flow determines the size of the cells which are so arranged that best performance coincides with most usual operating conditions.

These conditions are:

Minimum	12,000 gpm
Shutdown	30,000 "
Startup	80,000 "
Normal	96,000 "
Maximum	130,000 "
Super	140,000 "

It is planned to maintain the velocity of horizontal flow in the vertical cells. The friction loss in these cells is of the order of 4% of the total head available. The balance of this available head (about 51 ft.) is to be dissipated in 3 perforated plates (orifice plates) each converting about 17 feet of head into velocity which velocity is then dissipated in the following length of pipe.

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The purpose of this proposed arrangement is to insure that all orifices are under a positive head not less than the loss of head in the orifice plus the velocity head in the orifice. If this is done the pipe and orifice will run full, there will be no negative pressure and consequently there will be no cavitation or air pumping. The purpose of this particular cell arrangement is to permit each assumed flow pattern to build up a positive head above the orifice plates with a minimum of spilling over into adjacent cells.

It is not practicable to arrange cells and orifices to meet all flow conditions as they arise. Selected conditions only were met, it being assumed that other conditions would be of a transitory nature and would be endurable during their short duration.

Recent practice has been to provide duplicate downcomer facilities so that one could be in use while the other was being repaired or inspected.

It is proposed for this design to use a single main downspout to eliminate the cost of the extra unit. When necessary to inspect or repair the downspout a bypass line of about 14" in size sufficient for a maximum of 15,000 gpm will be provided so that low flows can be diverted around the main downcomer and into a crib or into the effluent line as may be desired.

This feature will limit inspection and repairs to the downspout to shut down periods when low flow can be tolerated.

A cost comparison between "C" unit with duplicate downcomers and "XX" unit with one downspout is attached.

Summary

Based on information and calculations gathered into this report, it is believed that one downcomer made of stainless steel and constructed of cells and orifice plates as sketched will provide a satisfactory unit and require minimum maintenance, as well as greatly simplify building construction.

The cost would be in the order of \$57,000 less than other proposals.

This design can readily be adapted to a pressurized effluent system with no change in characteristics of operation of the downcomer.

In case of error in design or change in operating requirements, a change of orifice plates, (which is readily done) will provide the required changes.

Venting requirements which introduce a health hazard are less than any other proposal. For low flows, venting is done entirely within the downspout. For maximum flows, the unit runs full and required venting is limited to gases released from hot water.

It is noted that theoretical calculations give a different result than Bernes & Petersen's test. Since it is possible to redrill the smaller hole that their method proposes, this smaller size is selected as adequate design.

Effort is being made to test the proposed design in a hydraulic laboratory. Design will be modified accordingly, if required, when laboratory data is available.

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Calculations

It was originally suggested that the downspout be constructed of many very small cells, so small and numerous that the hydraulic radius be nearly 1 (unity). In this case, all of the vertical head would be destroyed in friction as rapidly as generated.

However, King in Hydraulic Handbook, Page 59 states, "To obtain the maximum discharge, the intake must be submerged to a depth equal at least to the sum of the velocity head and the loss of head at entrance. The discharge is entirely independent of the slope of the tube." This condition could not be fully met under the conditions shown on Drawing SK-1-20148 and described in Paragraph 1 above.

Conference with engineers of the Bureau of Reclamation Hydraulic Laboratory at Denver modified the above design into a more simple structure shown on SK-1-20184 and outlined on attached diagram. This new proposal can meet the condition for full flow outlined in Paragraph 2 above.

In order to insure that entry conditions be met it was decided that selected flow conditions in the upper approach pipe be studied for depth of water and velocity and at these selected flows the velocity of the horizontal flow be maintained in the vertical section of the downcomer by means of suitable cells. The restriction to flow this requires was to be provided by orifice plates located as far under water as practicable. The calculations following indicate how this was done.

The calculated depth of flow in the horizontal approach pipe is determined by the following formula:

$$\frac{a^3}{T} = \frac{Q^2}{g}$$

where a = area of channel

T = width of water surface

Q = quantity flowing

(King Handbook, P-373)

g = 32.2

This can also be expressed

$$dc = \sqrt[3]{\frac{q^2}{g}} \text{ for each ft. of width}$$

where dc = Critical depth in ft.

q = Quantity flowing, second ft.

g = 32.2

(King Test P-220)

Calculated results and the curve therefore are given elsewhere herein.

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For cell #5, Nominal flow, 80,000 gpm

Velocity = 11.3 ft/sec. for this flow

178 sec. ft. $\div$ 11.3 = 15.7 sq. ft. Required Area

$\frac{48" \times 56"}{144} = 18.6$ sq. ft. Available in cells 1, 2, 3, 4, 5

#5 cell will not run full

#4 cell will run full at this flow.

For 96,000 gpm; Velocity = 12.0 ft. per sec.

214 sec. ft. $\div$ 12 = 17.8 Required Area

#5 cell will not quite run full.

If we assume our available elev. Hd. is 60' and our terminal velocity is 4' per sec., then total head to be lost is

60' - 4' = H_f = Total hd to be lost in orifices.

To determine H_f use passage 21" x 16" (#4) as example.

The hydraulic radius =

$$r = \frac{a}{P}$$

Where a = wetted area

P = wetted perimeter

(King P-253)

$$r = \frac{(21)}{42} \frac{(16)}{32} = 4.54"$$

Darcy's Formula for friction loss in pipe H_f is:

$$H_f = f \frac{L}{D} \frac{V^2}{2g}$$

(Rouse P-201)

Effective diameter "D" for above equation is

$$D = (4.54) (4) = 18.16" = 1.52'$$

(Rouse P-216 L 2)

Then $H_f = 0.015) \frac{65}{1.52} (2.2) = 1.4'$ Friction Head lost in entire length of Downcomer for this representative cell only.

Where 65' = Effective Length of Cell

1.52 = Effective D

2.2 = $V_L = \frac{V^2}{2g}$ = Velocity Head in Pipe

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Similarly calculations show that for 7" x 16" cell

$$f = 2.6' \text{ Lost Head}$$

Say we use 3' as average lost head due to friction in all cells
at all flow rates

Then

$$60' - 4' - 3' = 52' \text{ Head remaining to be destroyed.}$$

Assuming we use 3 orifice plates, then in each plate must be lost

$$52' \div 3 = 17' \text{ of total head to be lost in each plate.}$$

Now Coefficient of Discharge of an orifice is

$$C_v = .60$$

(King P-49)

We can safely assume that the velocity in an orifice is all lost and no energy is recovered on the downstream side due to turbulence on both sides of orifice. (Recovery, however, can be material under ideal conditions. See Chemical Eng. Handbook, 1934, Page 693.)

Using Barnes and Peterson's investigations of flow through screens as published in ASME transactions, we have these results:

$$A_T = \text{Area of Tube considered} \\ 7" \times 16" = 112 \text{ " } = .778 \text{ sq. ft.}$$

$$A_O = \text{Area of Orifice Required}$$

$$S = \text{Solidity Ratio} =$$

$$S = 1 - A_O/A_T$$

$$V_C = \text{Mean velocity head in the stream}$$

$$P = \text{Head to be lost}$$

$$\text{Then } \frac{P}{V_C} = \frac{17}{2.2} = 7.7$$

Referred to Fig. 3 Chart of above investigations:

$$S = 0.6$$

Since

$$S = 1 - A_O/A_T$$

$$0.6 = 1 - A_O/.778$$

$$A_O = .312 \text{ sq. ft.} = 45.4 \text{ sq. in. for a single orifice}$$

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Use 10 holes, then

$.312 \times 10 = .0312$ sq. ft. for each hole

= 2-3/8" Dia., 10 holes

Summary

10, 2-3/8" holes in each 7" x 16" cell in each of 3 orifice plates should raise water level to top of downcomer and allow flow with minimum freefall or other turbulence. It is not dimensionally practicable to use one orifice opening for each 7" x 16" cell. 10 orifices per cell works out as a good design.

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CRITICAL DEPTH

Flow			Q^2	$\div 32$	3	AREA		Velocity
gpm	Sec. ft.	Per ff of width			ft.	= inches	Ft.	
12,000	27	6.75	45.5	1.41	1.12	13.5	4.48	6.03
30,000	67	16.7	278.9	8.64	2.06	24.8	8.25	8.1
80,000	178	44.5	1980	.61.5	3.95	47.4	15.8	11.3
96,000	214	53.5	2860	89.5	4.45	53.4	17.8	12.0
130,000	290	72.5	5256	163	5.45	65.5	21.8	13.3
140,000	312	78.0	6084	188	5.73	68.7	22.9	13.6

TABLE OF CALCULATIONS FOR CRITICAL DEPTH
IN UPPER APPROACH PIPE

(BASED ON KING - P-220)

CHECK: -

Using Cameron Data, P. 68

$$Q = 19,636) (K) (d^2) h$$

Q = Volume Flowing 4200 gpm

K = Coeff. = .61

d = Orifice Dia. in inches

L = Head on orifice = 17'

$$4200 = (19.636) (.61) (d^2) (4.12)$$

$$d^2 = 85.4 \quad d = 9.22" \text{ for 1 Hole}$$

Area = 66.7 sq. in. One orifice

10 Holes = 6.67 " per hole

= 2-15/16" Dia. each hole

(Theoretical Value)

CHECK: -

Using Russell, P-76 For Theoretical Values

$$Q = C_d \quad a \quad \sqrt{2gh}$$

Q = Volume = 9.35 Sec. ft.

C_d = Coeff. of Discharge = .61

h = Head = 17'

$$9.35 = (.61) (a) (33)$$

$$9.35 = (20.15) (a)$$

a = .464 sq. ft. For one hole

= 66.8 sq. in. or (2-1/8") For one hole

For 10 Holes = 2-15/16" Per Hole

(Theoretical Value)

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Acknowledgement

Much help was obtained from W. H. Martin, Head, J. W. Ball, and D. J. Herert, Engineers of the Bureau of Reclamation Hydraulic Laboratory at Denver, in obtaining ideas and developing calculations. It was their suggestion to attack the downcomer from the screening (orifice plate) angle.

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