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DESIGN OF SANITARY AND STORM SEWERS
SEWAGE FINAL DISPOSAL

by

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I INTRODUCTION

It has been recognized by the sanitary authorities all over the world that it is of paramount importance to remove the solid and liquid wastes produced in urban communities as fast as possible and to dispose of them in an appropriate and approved sanitary manner.

Domestic sewage is carried away by the so called sewer systems which can be designed either to take care only of the domestic sewage (separate system) or to carry away, at the same time, the water produced by rainfall (combined system).

If for economical reasons it is decided to construct separate sanitary sewers instead of combined sewers, there is still the problem of storm water left behind and a new system has to be constructed to dispose of this flow.

There are few areas in the world where rain never falls and one example is Lima, Peru, in South America which has no need of storm sewers.

The selection of separate or combined sewers is a matter of economics. At present practically all the large communities in the world are discharging their sewage effluents into existing water bodies which continue to be used afterwards. In some cases such water bodies are used for irrigation, in others for drinking, mainly in communities located down-stream. They may also be used for bathing, swimming or water recreation.

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In general it is necessary to treat the sewage before emptying it into natural water courses and this extra cost will militate against the use of combined systems due to the impossibility of treating all the storm water plus the sanitary flow. Nevertheless we find combined sewer systems serving large communities for more than sixty years. These sewers are causing sanitary problems in their final discharge to rivers, lakes and in the sea due to the rapid increase of the population served. Public health authorities are gradually making compulsory the construction of treatment plants to avoid unhealthy conditions although not all the effluent is treated.

It appears to be the fact that one of the prices paid for progress is a deterioration of raw water quality due to the vast and increasing amounts used, re-used and recycled.

In combined sewer outfalls it is difficult to decide the amount of flow of mixed sewage and storm water that should receive proper treatment and it is frequently accepted to treat the dry weather flow in addition to the initial part of rainfalls. The excess of flow is then diverted through special designed weirs and mixed with the diluting water body already increased by the storm water drained into it.

II DESIGN OF SANITARY SEWER SYSTEMS

Sewer systems for urban communities should be designed to serve the maximum population expected for the design period chosen (thirty to fifty years). Short design periods are acceptable only for areas where the construction of supplementary future sewer pipes is easy.

The following sewage flow data has importance in the design of sewer systems:

- Minimum hourly flow
- Minimum daily flow
- Medium daily flow
- Maximum daily flow
- Maximum hourly flow

The minimum and maximum hourly flows are necessary for the design of sewer pipes in order to maintain self-cleaning and not erosive velocities.

The principal sources of inflow in a separate sewer system are the following:

- House sanitary flow
- Industrial liquid wastes
- Ground water infiltration
- Storm water infiltration

The mean house sanitary flow is accepted to be 80 per cent to 90 per cent of the per capita drinking water consumed per day at the beginning and at the end of the design period. It is also acceptable to deduct the per capita mean sewer flow from existing installations in areas with similar characteristics. Maximum and minimum flows are deducted by experience in existing services and applied to new designs. The maximum flow is found to be 1.5 to 3 times larger than the mean value and the minimum is around 1/3 of same.

Industrial liquid waste contribution to public sewers has to be estimated in each case taking into consideration all the available information as well as the expansion of industries in the future. The liquid waste of industries has large variations in their composition and volume according to the kind of industry. In some cases it is necessary to provide a special permit or consent for discharging such wastes into the sewers. This permit will spell out the accepted daily volume, the chemical and bacteriological conditions, the maximum temperature and the range of variation of pH value.

Infiltration of gound water and storm water into sewers depends on the permeability of the ground, the water table elevation, the relative location of the sewer pipe in it, the type and quality of pipes and their joints, and finally the existence of small fissures in the pipe body or the existence of loose joints due to heavy traffic and earthquakes. In some countries of South America where frequent earthquakes occur, a daily infiltration of up to 20 m^3 per kilometre of pipe is accepted.

1. Location of Sewer Mains

Topographical condition of the area to be sewered determines the districts to be drained into a projected sewer main. Population density is deducted from the city Master Plan and information available from housing authorities. At least two figures should be forecasted, density at the initial stage of sewers operation and density at the end of the projected period.

When designing sewer main diameters and slopes it is important to take into consideration the future expansion of the area to be served and the change of all the factors involved in the determination of the per capita flow increase through the projected period.

Sewer mains should be located, when possible, in the centre of the street, except when the topography shows the need of sewer construction near one side of such street. Another exception is when two parallel pipes are used, one on each sidewalk which is more economical than one sewer at the centre of the street due to the length of house connections.

Sewer pipes should be constructed lower than water mains in order to avoid cross connections. The direct connection of sanitary fixtures to sewers should be avoided specially when these appliances are fed with drinking water. Also ventilated siphons ought to be installed to eliminate cross connections.

Maximum precaution should be taken when sewers are designed to pass near water wells. In such cases it is advisable to construct sewers with wrought iron or ductile iron pipes in the vicinity of the water wells to protect them against possible sewage leaks.

2. Sewer Pipes

Sewer design standards accepted by several countries establish minimum public sewer size and minimum size of house connection pipe. In general these minima are 6" and 4" respectively.

It is recommended that a uniform pipe slope should exist between manholes and that the minimum slope acceptable be the one that will produce self-cleaning velocity in the pipe at minimum flow. The larger the diameter of sewers the lower are the minimum slopes required.

The material used by the manufacturers of sewer pipes are:

- Concrete
- Vibrated cement
- Vitrified clay
- Asbestos-cement
- Wrought iron - ductile iron
- Protected steel.

Any of these materials are acceptable for sewer pipes provided that they will meet local conditions such as septic sewage conditions, the quality of industrial waste-water, ground aggressivity and external load.

When the available commercial pipe is not able to resist the external load it is accepted to reinforce such pipes with concrete, reinforced concrete or other materials. Another kind of material should be used when this practice is not applicable or does not meet the structural requirements.

3. Sewer Manholes

The construction of manholes for inspection, operation and maintenance is necessary in all sewer systems and they should be located at the intersection of pipes and at the points of change of slope. Manholes can be replaced, in some cases, by inclined pipes with covers that will allow the introduction of cleaning equipment.

The necessary measures should be taken to avoid flooding of sanitary sewers with storm water or other kind of water through the manhole covers. This problem can be eliminated by constructing manhole covers at higher levels or making them water tight.

4. Inverted Sewer Siphons

Inverted siphons are designed to clear obstacles encountered by sewers when laying them with the designed slope. They may run across gas, electric, water or storm facilities without the possibility of avoiding them by changing the slope. These siphons should be easily inspected and, whenever possible, two parallel pipes ought to be designed, each leg with enough capacity to hold the normal flow.

If the sewage has a great percentage of settleable solids (sand, soil, etc.) it is advisable to add sand catching basins, upstream or downstream of the siphon, to be cleaned periodically. The lower leg of the siphon should be sloped towards this sand catching basin.

5. Hydraulic Design of Pipes

Sewer pipes are assumed to flow at full capacity with permanent and uniform flow. The "n" coefficient for the Manning formula and for different kinds of material is as follows:

Concrete	n	0.015
Vitrified clay	n	0.010
Asbestos-cement	n	0.010
Wrought iron	n	0.013

6. Project Information

Projects for water supply in urban communities should include the following documents for approval:

i. Description of the system with historical résumé of geographical, political and socio-economical developments.

ii. Engineering description of the different parts of the job with supporting design estimates.

iii. Administrative and technical specifications for construction. Draft of Construction contract.

iv. Volume of work and cost estimates with justification of unit prices.

v. Layout plans at a minimum scale of 1:5 000 including topographical levels in each manhole. Profiles of pipe lines and interceptors. Detailed plans for special structures at a minimum scale of 1:50.

III SEWAGE PUMPING STATIONS

When sewage has to be elevated it is necessary to design sewage pumping stations. In designing sewers on flat land it is necessary very often to use booster stations for large interceptors in order to avoid dip excavation and high construction cost.

It is also advisable to use pumping stations to inject sewage into the sea for final disposal when multi-outlets diffusers are designed.

Another case where pumping stations are required, for economical reasons, is illustrated in the design of sewage treatment plants at the end of long interceptors in flat land.

Within a treatment plant it is necessary to install pumping stations to recirculate partially treated sewage.

In general terms we can classify the sewage pumping stations as follows:

- Affluent pumping
- Effluent pumping

Affluent sewage pumping stations are those that are receiving raw sewage to be elevated to upper levels in the same sewer line, or to a treatment plant or directly to a receiving water body. When sewage is elevated to a treatment plant, the pumping station is usually located at the treatment plant site, unless the sewer main would reach the plant too deeply and one or more booster stations are required upstream. This latter condition should be studied in detail comparing with the cost of alternative solutions. Screens are advisable to protect pumps from large solid materials and sand catching basins are also recommended for raw sewage to avoid rapid wearing down of the mobile parts of the pumps. Finally emergency outlets should be designed to protect the pumping station against flooding in case of failure of power.

Effluent pumping stations are more simple to design and they will not require the protection described above for affluent pumps. The treated water handled by these pumps is "cleaner" than raw sewage and the pumping equipment has more efficiency. In some special cases it is advisable to have affluent and effluent pumps in a sewage treatment plant. The designing engineer should make the analysis of the different alternative solutions and should decide which combination is the most convenient and least expensive.

1. Sewage Pumps

Centrifugal pumps are generally used for sewage elevation. Their mobile parts are of the radial or diagonal type according to the required capacity, and in their installation the vertical model without suction shaft is preferred.

Pneumatic ejectors are recommended for small sewage elevation and for small flow due to their low efficiency (15 to 25 per cent). Pneumatic ejectors can replace sewage pumps only for elevation of small volumes. Their application in the Americas has been reduced considerably in the last few years due to their limitations.

Rotors in raw sewage pumps should be rounded without sharp angles to avoid retention of rags and solids.

For a longer wear it is desirable to have the closed type of rotors.

Sewage pump efficiency is expected to be around 85 per cent for average sewage flow and could drop to 60 per cent for small installations. The low efficiency of these pumps is the compensation paid for securing the passage of solids up to 5 to 6 cm in diameter.

Pumps with normal efficiency for large variation of flow is recommended when the sewage elevation is high because they will give better service than pumps with good efficiency for only a restricted range of flow. Such suggestion is important when selecting pumps from the various manufacturers' catalogues.

The relation between capacities of pump and a sewage storage tank should be such that the latter will not produce frequent starts and stops of pumps and eventually will feed a fairly constant flow of sewage to the treatment plant, should a treatment plant be necessary.

Rags, plastic pieces and fibrous material carried by raw sewage constitute great problems for pumping stations.

The number of pumps to be installed is determined by the Q-H curve of the sewage system. We can select either all the pumps of the same capacity to cover the "Q" demand by stages, or different size pumps according to the demand curve. The selection of equal capacity pumps has the advantage of making it possible to rotate them, trying to level up the number of working hours, obtaining uniform wearing down and reducing the necessary stock of spare parts.

The angular velocity of sewage pumps runs from 1 200 r.p.m. to 1 800 r.p.m. It is generally recommended to select pumps of constant velocity. Nevertheless pumps with variable angular velocity will reduce the number of necessary pumps, produce a more even flow and reduce the size of the suction tank, although they are more expensive and more elaborate. Final selection is left to the designing engineer who has to evaluate all the facts involved.

The underground structure for sewage pumping stations is costly and difficult to construct, due generally to the depth of incoming sewers. Circular-shaped structures are recommended when their construction is done by the sinking method under special soil conditions and high water table.

If the geological formation is favourable it is recommended to design rectangular-shaped structures because it is easier to use the available space.

Suction tanks should have access only from the outside to avoid environmental pollution of the rest of the station. Whenever possible it is preferred to have two units of such tanks in order to facilitate their maintenance.

The smallest and more economical floor is achieved in pumping stations by using vertical sewage pumps, having the additional advantage of electrical motors set at the top, above the flooding level.

The pumping house should be well illuminated and ventilated. In large installations it should be provided with a bridge crane or facilities for removing the pumps when necessary.

Automatic pump control should be supplied in sewage pumping stations for an efficient operation. They are usually installed at the suction tank side consisting of floaters which command pneumatic or electronic contacts. Floaters can operate efficiently if they are housed in proper tubes or pits, isolating them from water current action. This latter system is reliable when used in treated sewage but could have troubles when handling raw sewage. To avoid this problem a pneumatic system that operates under air pressure has been devised bubbling air continuously at the submerged end which eliminates stoppage. It operates the pump controls with the change of water level by changing the air pressure and thus contacting the starter or the still position. The sensibility of this device is around 6 cm of water level variation. The pneumatic control system is cheap, reliable and has no mobile parts in contact with sewage.

The electronic sewage pump controls are usually of the submerged electrode type, having two units for each pump and located in such a manner that they will start the pumps at different sewage levels. This electronic system is advisable when there is a continuous flow and few pumps are required. The electrodes are bound to be covered by grease, foam and floating materials, requiring periodical cleaning to secure an efficient service.

IV STORM SEWER SYSTEMS

Storm sewer design is based on pluviometric statistics and the relation curve "intensity-duration time" of rainfall in the area to be drained. If there is no information available regarding intensity-duration of rainfall we can assimilate the pluviometric condition of the area under study to another where statistic figures are available. If this similarly does not exist then a proper study should be made to produce the basic data for design.

In large areas with high storm intensity it is not practical nor economical to design sewers to take care of the maximum flow with the maximum intensity giving a 100 per cent security. When a large number of years with pluviometric statistic is available the designing sanitary engineer will establish the acceptable intensity with a feasibility study. Storms over the one selected as a maximum to enter the sewer system will produce temporary inconvenience and flood in low lands. All these factors should be evaluated by the designing engineer.

To reduce the cost of storm sewers, in some cases, open channels properly lined have been constructed, as in Singapore. Unfortunately these open canals interfere with traffic and use an important area of the street space. At the same time it is unavoidable to prevent that a great deal of city solid wastes be thrown into such channels bringing about a serious sanitary problem.

Storm sewer conduits can be designed to be placed immediately under the surface of the ground, avoiding costly excavation.

When street storm inlets are connected to combined sewage systems, they should have a hydraulic siphon to prevent sewage ventilation and bad odours from coming out of these openings, and when street siphons are provided then special care should be taken to eliminate mosquito breeding places by periodical fumigation with insecticides or by petroleum spreading

Street storm inlets are simple and without siphon when connected directly to storm sewer system, they should be kept clean during rainy season.

The storm pipe system is hydraulically designed on the same engineering pattern used for separate sewers. New feeding areas should be connected at the proper topographical points, with pipe slopes lower than those used for sewage flow.

In general the total length of a storm sewer system is less than that of the sewage system, because it is possible to find proper outlets into running water in different places along the line, which is not allowed for sewage effluent.

V SEWAGE TREATMENT

1. General

Domestic sewage contains less than 0.1 per cent of suspended and dissolved impurities which represent less than 1 000 ppm and the rest is water. The organic matters take advantage of the existing oxygen in water to transform albumin, protein and carbon hydrates into stable products like carbon dioxide, nitrates, sulphates and water. If the existing dissolved oxygen in water is exhausted, the aerobic bacteria die and the anaerobic ones remain alive to extract oxygen from the chemical and organic compounds with production of obnoxious gases and decaying organic matters. When sewage gets to this latter stage it is said to be in septic condition, which could occur a few hours after sewage production. If sewage is mixed with receiving water (dilution in rivers, lakes, etc.) a biochemical cycle takes place similar to that indicated above, but relying now on the additional oxygen coming from the receiving water body.

Analysis of domestic sewage made in USA shows the following composition in percentage:

Organic matters	50 per cent
Mineral matters	50 per cent
Settleable matters	20 per cent
Suspended matters	80 per cent
Settleable organic matters	67 per cent
Settleable mineral matters	33 per cent
Suspended organic matters	50 per cent
Suspended mineral matters	50 per cent

When the receiving water body is not able to supply all the dissolved oxygen demanded by the incoming sewage (BOD) it is necessary to produce artificial reduction of such BOD to the limit of the oxygen balance. For this purpose special sewage treatment plants are designed.

The raw sewage reaching a treatment plant shows flow fluctuations varying from 35 per cent to 300 per cent of its mean value, when coming from separate sewer systems. In the case of combined sewage system, the maximum flow could reach up to 100 times the average dry weather flow. Due to this large variation of flow in the latter case it is recommended to conduct to the treatment plant a maximum flow three times larger than the mean dry weather flow.

This compromise limits seriously the efficiency of a treatment plant operating at the end of a combined sewer system. There is no assurance of a proper sanitary protection of the receiving water body. On the other hand it is certain that better sanitary protection is obtained for receiving waters with treatment plants designed to treat sewage from separate sewer systems.

For these reasons the public health authorities emphasize the construction of separate sewer systems instead of combined ones, whenever possible, specially if a treatment plant has to be constructed.

2. Sewage Treatment Plants

Sewage treatment plants have two main objectives:

i. Retention of floating materials and settleable solids.

ii. Reduction of BOD to produce acceptable effluents for final disposal by dilution or otherwise.

Due to the great advance on sewage treatment techniques any condition can be met from simple settling, up to the conversion of sewage into potable water.

The cost of treatment increases rapidly when "cleaner" effluents are required, which makes it of great importance to ensure proper determination of the degree of purification that will satisfy the local pollution problem.

Sewage treatment procedures can be classified as follows:

- Pre-treatment
- Primary treatment
- Partial treatment
- Complete treatment

2.1 Pre-treatment

This consists of the removal of such wastes and rags that would prevent or jeopardize the action of more advanced treatments.

Racks or coarse screens composed of bars placed vertically or at an angle to the horizontal will retain dead animals, rags, metal scrap, pieces of wood, and floating solids. Fine screens also remove a part of the smaller suspended solids.

Efficiency of coarse screens is very low and it is not taken into consideration. For fine screens the efficiency could be about 10 per cent in removal of suspended solids.

2.2 Primary Treatment

This consists of the removal of settleable solids by sedimentation. Sedimentation is a highly important process in sewage treatment and it is employed as primary treatment at most plants. When conditions with respect to dilution are favourable, sedimentation may be the only treatment given in addition to pre-treatment. An efficiency of 50 per cent to 60 per cent in removal of suspended solids is expected.

2.3 Partial Treatment

Partial treatment or chemical precipitation embraces all primary treatment procedures, accelerated and improved by the use of coagulants (alum, lime and ferrous sulphate). Quick and thorough mixing of chemicals and sewage is necessary, and this should be followed by slow-motion mixing for 10 to 30 minutes to allow flocculation. These requirements can be satisfied by putting baffles in mixing chambers or by mechanical agitation. The efficiency expected is around 45 to 80 per cent in BOD reduction and 65 to 90 per cent in suspended solids reduction.

2.4 Complete Treatment

Complete treatment includes all the secondary processes with biochemical action obtaining a considerable reduction in BOD. Large reduction of solids is achieved by flocculation of primary treated effluent followed by secondary settling. Partial recirculation will increase efficiency.

The use of trickling filters and activated sludge methods is frequently found in secondary sewage treatment.

If the effluent of a complete treatment process is expected to be free of bacteriological pollutants, it is necessary to add disinfectants such as chlorine with residual action to guarantee the protection of beaches, rivers, lakes or any receiving water body.

The effluent of a complete sewage treatment plant can still undergo further treatment as sand filtration with pre and post chlorination thus producing finally potable water.

The following table contains the reduction in percentage of suspended solids and BOD expected in each of the various treatment processes:

Process	Reduction per cent	
	Suspended Solids	B O D
Primary treatment	40 - 70	25 - 40
Primary treatment with chemical precipitation	65 - 90	45 - 80
Complete treatment with trickling filters	75 - 90	80 - 95
Complete treatment with activated sludge	85 - 95	85 - 95
Complete treatment plus sand filtration	90 - 98	85 - 95

All the above mentioned sewage treatments are processed in special designed structures with adequate retention periods and facilities for addition of chemicals.

Even when there exist several registered commercial patents for sewage treatment processes, there is no need of using exclusively such patents, paying high royalty when local sanitary engineers could design the plant to satisfy local conditions and importing only the necessary equipment not available in the country.

It is most important that the national sanitary engineers be acquainted with all the parameters involved in sewage treatment plant design.

Small sewage treatment plants for rural communities should be simple and should not require specialized workers for operation and maintenance. Large installations need careful technical attention and specialized workers are demanded for operation and maintenance.

3. Stabilization Ponds - Sewage Lagoons

During the last decade sewage lagooning has gained great popularity due to its economical and simple procedure of sewage handling. It is based on the high and free oxygen production when certain algae are present in sewage. These algae grow because of the organic food provided in the sewage and the presence of sunlight. In the algae growing process there is a large production of oxygen which is used to satisfy the sewage oxygen demand (BOD) for proper stabilization.

The oxidation of organic matters in sewage lagoons is anaerobic and slow at the bottom and aerobic and accelerated at the upper levels. The oxidation process is performed mainly by aerobic bacteria converting organic carbon into carbon dioxide while at the same time algae are transforming, by photosynthesis, the carbon dioxide into cellular matter.

It is possible to regulate the speed of these processes in order to obtain an effluent with low organic content and small BOD.

The most important factors in sewage lagoons design are the following:

- Prevalence, intensity, duration and penetration of sunlight in sewage.
- Depth of lagoon in relation to sunlight penetration.
- Rainfall and evaporation in the area.
- Permeability of land that will insure the production of a lagoon with the amount of sewage inflow into the dam.
- Assurance that no ground pollution will occur during the operation of sewage lagoons.
- Algae production scheme.

There are examples in different parts of the world of sewage lagoons replacing sewage treatment plants.

One of the restricting factors in this process is the large area needed. One hectare (2.47 acres) for each 250 persons served is approximately required, namely, a community of 10 000 inhabitants will need forty hectares of land located at least 500 m away from the nearest housing concentration.

The efficiency of sewage lagoons is 80 per cent to 90 per cent in reduction of BOD and 30 per cent to 70 per cent in removal of suspended solids.

The design standards for sewage lagoons are changing according to the available investigation in different parts of the world. Nevertheless some figures can be given to guide the preliminary designs:

Load : 100 persons/acre
10 000 gallons/day/acre
17 pounds/day/acre of BOD

Stabilization ponds are used for municipal sewage and industrial wastes treatment. The efficiency and economy of this method of final sewage disposal depends on local environmental conditions which varies from one place to another. Practical experience shows that sewage lagoons can be used in all kinds of climates, being more favourable to the tropical one.

For all these reasons it is most advisable to coordinate and emphasize the need for investigation of sewage lagoons so as to establish the proper parameters for the various conditions under which this method could be used.