The influence of man-made loads on selection of structural form

Autor(en): **Mathieu, Henri**

Objekttyp: **Article**

Zeitschrift: **IABSE reports of the working commissions = Rapports des commissions de travail AIPC = IVBH Berichte der Arbeitskommissionen**

Band (Jahr): **36 (1981)**

PDF erstellt am: **25.05.2024**

Persistenter Link: https://doi.org/10.5169/seals-28269

I

The influence of man-made loads on selection of structural form

Influence des charges d'origine humaine sur le choix du système et la forme d'une structure

Einfluss der auf den Menschen zurückzuführenden Einwirkungen auf die Wahl der Tragwerksform

Henri MATHIEU
Ingénieur Général des Ponts et Chaussées
Ministère de l'Environment et du Cadre de Vie
Bagneux, France

SUMMARY
In the choice of structural forms, man-made loads often have a rather limited place. Their influence mainly depends on their variability and concentration in space

RESUME
Dans le choix des formes structurales, les charges d'origine humaine ne tiennent souvent qu'une place assez modeste. Leur influence dépend principalement de leur liberté et leur concentration dans l'espace.

ZUSAMMENFASSUNG
Bei der Wahl der Tragwerksform finden die auf den Menschen zurückzuführenden Einwirkungen meist wenig Beachtung. Ihr Einfluss hängt vorwiegend von ihren Beweglichkeiten und der Konzentration im Raum ab.

1. INTRODUCTION

Man-made loads (m.m.l.) are rarely given in technical articles as a justification of the selection of one structural form. Yet the erection of a pedestrian bridge, road bridge and railway bridge performed on the basis of identical constructional data (excluding loads) would result into variations, usually notable and sometimes very wide, not only in structure size or constructional details, but also regarding the structural form.

2. SIGNIFICATION OF "MAN-MADE LOAD" (m.m.l.)

2.1 Referring to modern concepts, the meaning of the word "load" is extended here and covers the words "action" (i.e. imposed forces or deformations) and "situation" (including such phenomena as fire, impact, partial destruction).

2.2 The term "man-made" is to be understood as contrary to the word "natural" (natural actions have been dealt with in prior introductory reports); the reciprocal influence of natural circumstances and m.m.l. is not considered here.

2.3 Human activity plays a major part in all permanent actions, such as structure and superstructure dead weight, prestressing, etc. However, most of these actions will not be taken into account further on, inasmuch as, generally, they are consequences resulting from the selected form; we shall therefore consider mainly "loads" which directly (i.e. independently of the selected design) constitute data to be taken into account in the determination of the form. They consist essentially of :

- among variable loads, the working loads which cover traffic and occupancy loads along with many others : industrial, hydraulic loads (for instance, in dams and reservoirs), etc.;

- most accidental actions, particularly the actions which result from accidents.

However, it will be shown later on that the loads resulting from the form selec tion interact with the form, either directly or as a consequence of some erection phases.

3. - HOW ARE m.m.l. DEPENDING ON HUMAN ACTIVITY ?

3.1 The m.m.l. dependence on human activity may be of different nature; two extreme cases are to be distinguished :

a - m.m.l. depending upon a number of human decisions, as for instance the weight of a number of vehicles or persons on a bridge or a floor;

b - m.m.l. depending upon one human decision, as is the case for instance when vehicles over a given tonnage are forbidden admittance to a park or a bridge by a guard, or when the driver of a heavy vehicle takes a forbidden route.

3.2 This discrimination leads, according to modern concepts, to different responses as regards safety against such actions, namely :

- in the first case, m.m.l. are dealt with like natural actions : design is carried out as a function of a statistical estimate of the magnitude of actions; in this case the actions are variable loads, and the applicable distribution laws are similar to those of natural actions;

- in the second case, the response involves other provisions, which may be independent of structural arrangements : for instance, assignment of responsibilities and controls; then infractions to the regulations are taken into account as accidental actions.

It can therefore be deduced that,as a function of the response to the m.m.l., their influence on the selection of structural form may be much reduced, up to zero in some cases. Thus the possibility of vehicle impact can be dealt with through a safety barrier which will, if borne by the structure, deaden and localize the force, whereas it will cancel any influence of this action on the design, if it is not borne by the structure.

3.3 However, inasmuch as a risk for the structure has been admitted, the attempts at reducing its consequences will have an influence on the selection of the structural form, which must be :

- robust (for instance, an admitted risk of partial destruction of a building by a gas explosion leads to select a form excluding "progressive collapse"),

- fit for repairing (for instance, after an impact of medium intensity).

4. MAN-INDUCED CONSTRAINTS, BESIDE ACTIONS, APPLIED TO PROJECTS OF STRUCTURES.

4.1 It is worth mentionning, aiming at a thorough study of the problems of selection of structural forms, which are not dealt with in any specific report, the selection of structural form is frequently conditionned, to a large extent, by constraints which cannot be identified to actions, environment or material, some of them being of human origin.

The most important are doubtless geometrical constraints.They may be mainly ascribed to environment. However, some of these constraints may proceed from traffic, as for instance in the case of a road below which a building is contemplated; such constraints may be related to m.m.l. Such is also the case of constraints resulting from the necessity of placing ducts within structures.

4.2. The range of constraints, induced by man, which cannot be considered as actions, is very wide. Some examples in proof thereof are given as follows.

a - Aesthetics is a purely human concern, which does not regard the choice of material only (see Session 3); it exerts a direct influence on designs, even on the selection of the forms. Such influence is the most direct where the structural shape can almost be identified with the construction shape, as in the case of bridges.

b - Noise (a consequence to human activity) and the resulting need of protection against noise (a human requirement) may lead to provide phonic screens on a bridge. Then, in a particular case near Paris, the structural form was selected so that it could include these screens; an aesthetic concern played an intermediate part in this selection.

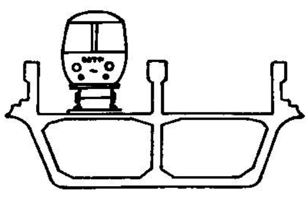


Figure 1

Likewise, in crossings for game animals above motorways, the structural form selected included equipment designed to protect the animals from the traffic light and noise.

c - Fires usually result from human activity, but they are not really loads, although they often involve high imposed deformations : the result is mainly strength losses. They may be taken into consideration in the selection of the form more or less like the other accidental forces.

These various man-made constraints will not be further studied in the following.

5. GENERAL PROPERTIES OF m.m.l.

5.1 These properties are related to their place in various qualitative classifications of actions, the main ones being defined in the Model Codes of International Technical Associations (notably the Volume I of J.C.S.S.). We shall therefore deal with these first.

5.1.1 We have already seen that, regarding the well-known, most usual classification of actions as permanent, variable and accidental, we shall consider variable and accidental actions mainly.

5.1.2 Actions may be taken into account as dynamic, depending on the structure : often, as regards accidental actions, rather seldom, in the case of variable actions. This may influence the form selection : some actions must compulsorily be considered dynamic (certain industrial loads), but for other actions the aim of the selection may be to consider them as quasi-static (many traffic loads) to reduce their dynamic majoration factor. Effectively, in this case, the fundamental period of the structure should be rather short; the form must therefore be selected so as to ensure a proper stiffness.

5.1.3 Almost all the m.m.l. considered here are direct actions (imposed forces). In the exceptionnal case of a m.m.l. with indirect action (imposed deformation), this feature would lead to select a form flexible enough.

5.1.4 A last general classification of Standard Codes discriminates free actions and fixed actions. In fact, this classification, though sufficient for the use of influence lines and surfaces, is very basic. It will be shown, that the structural form depends largely on this classification, which should therefore be refined. More precisely, we can discriminate :

- immutable and determined position loads,

- moving loads and/or undetermined position loads, and, in such cases, different degrees of mobility (or indetermination) :

    . perfect linear mobility (loads on rails),

    . approximately linear mobility (road loads),

    . total freedom in two directions (loads on floors).

Mobility is mainly a property of loads concentrated on small areas; we shall see later on (§ 5.3) the problem of concentration.

5.2 Many other qualitative classifications are possible (see for instance Manual of structural safety, C.E.B Bulletin 127, pages 249 to 253). We shall indicate some other distinctions and general characteristics of m.m.l. as follows.

5.2.1 Variable m.m.l. are practically always more or less intermittent, they almost never happen to be continuously applied during the whole lifetime of structures.

5.2.2 Among variable m.m.l., some of them give rise to long duration applications, either in a single occurrence, or by cumulating several occurrences. The other ones and the accidental m.m.l. may be said short-duration m.m.l. With materials likely to creep, long-duration loads can lead to select stiff forms in order to prevent excessive deformations. Here is an example of the relationship between action and form, conditional and linked to other data.

5.2.3 It is to be noted that m.m.l. are almost always unfavourable (as they draw the structure closer to its limit states).

5.2.4 As variable m.m.l. are largely due to gravity, they are essentially directed vertically downwards *; however, some of their components may be horizontal, very important (reservoirs, silos) or secondary (traffic loads); even secondary components can exert a notable influence on the form.

Accidental m.m.l. may be horizontal, more or less freely directed.

5.2.5 A final distinction is made between loads which depend only on functionnal construction data (notably occupancy and traffic loads) and which are therefore independent of the structural form, and loads depending on the form. This is the case of water pressures in a tank : as the structural form is generally identified to the construction form, the pressures perpendicular to the walls necessarily vary with the form; in this case, the form is often selected as a function of this dependence (see § 8.2).

5.3 On the other hand, the influence of m.m.l. on the form depends largely on their concentration. An actual classification is not possible in this case; we shall show the variety of the cases with some examples :

a - for a single load, all concentrations are possible between two extreme cases :

- uniformly distributed load (actual case)

- load concentrated at one point (asymptotic case).

Moreover, the load density can also be non-uniform on the loaded area.

b - estimating the concentration is still more complex in the case of multiple loads, as it depends not only on the concentration of individual loads, but also on their number and spacing.

6. MODELIZATION OF LOADS.

In fact, when dealing with more or less free and more or less concentrated loads, the loads themselves are not introduced, generally, into the designs; these take into account very simplified models, which fit more accurately the above description. This is a modelization in space, and the structural form is selected with reference to such models.

* An exception is the variation in earth pressure due to variable loads applied on the backfill.

These models are selected in order to generate effects equivalent to those generated by actual loads in the structures. Actually, this aim is never perfectly reached, even though, with a view to a greater accuracy, certain m.m.l. are represented by several mutually exclusive models, taken successively into account: for instance, a model of distributed (generally uniform) loads, and a model of highly concentrated loads. Inaccuracy is generally rather small (maybe of the order of 10 %) as regards principal effects such as bending moments in critical sections; but it may reach 20 to 40 % for other effects, such as shear forces or local moments. Such inaccuracy depends in a large measure on the selected structural form; the compatibility of the model with the selected form is a factor of the form selection which, practically, is almost never considered in the selection of the form, but which should be considered a posteriori at least, in order to check the compatibility, mainly so when the eventuality of a new form is being contemplated. Sometimes, however, a loading standard gives a precision: for instance, it states that the model must be complemented by a concentrated load, in the case of a floor consisting of a slab and joists.

An exemple of the sensibility of the form to modelization is shown is the figure opposite : the modelization of the accidental impact of a boat against a bridge is limited to a force applied to its piers in the river; exclusive application of this model could logically lead to place the piers on the banks, and to bring the deck very close to water at both ends (the model did not include the application of forces to the deck, whatever the deck level above water). Obviously enough, the deck would be subjected, in case of shock, to accidental forces smaller than those applied to the pier, since they would be applied by the boat superstructures; nevertheless, it appears clearly that the form obtained by pure and simple reference to a model of the action may lead to safety problems.

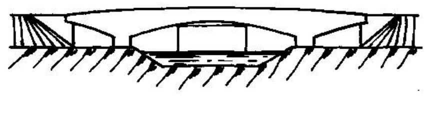


Figure 2

As the structure also is modelized for design, it must be ensured that such modelization does not introduce excessive inaccuracy. The selected form must enable to comply with this condition.

7. RELATIONSHIPS BETWEEN MODEL PROPERTIES AND THE SELECTION OF THE STRUCTURAL FORM.

Now we shall see, for each particular m.m.l., which general properties, according to its usual modelization, it is accredited with in the selection of the form.

Information on this, for variable then for accidental loads, is gathered in the two following tables.

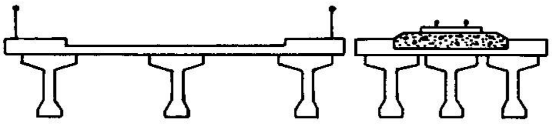
LOADS	MODELS		CONSEQUENCES
	PRINCIPAL LOADS	SECONDARY LOADS	
1 - VARIABLE			
Loads on floors (for dwellings, offices, stores, parkings, etc.) Very numerous cases are to distinguish numerically according to the structure intended use : passages, stairs, archives, libraries, education, entertainment, medical attendance, etc., see the draft for ISO 2103	Static, free loads, vertical downwards, represented by a double system of forces : . uniform distributed forces (principal effects) . concentrated forces (local effects)	Conventional component (representing also certain resistance requirements), with any horizontal direction, between 1 and some % of the principal loads	The double system of principal loads is qualitatively identical for almost all these loads; only the magnitude of forces varies according to the utilization; thus forms are fairly similar for all intended uses.
Industrial loads (for factories, sheds, wharfs, marine structures)	Same types of models as in the case of loads on floors. Besides, possible specific loads are defined individually in each particular case (heavy equipment, travelling bridge cranes); these loads are often fixed or guided, sometimes they are dynamic.		Structural forms may differ from those of similar constructions, due to : . either very different geometrical constraints, . either a very different magnitude of free loads, . or the existence of fixed or guided loads, . and sometimes isolated supports for dynamic loads
Traffic loads : - roads - rail - planes	Multiple systems of the same types as the systems of loads on floors, sometimes simplified into mixed systems (concentrated loads added to distributed loads). Sometimes the freedom of road loads is restricted, but only rail loads are currently considered as guided.	Braking components, centrifugal components, etc ..., with fixed direction	

- pedestrians, cycles	Single system of uniform loads; sometimes a concentrated (usually accidental) load is also contemplated.	Neglected	
Water pressure in dams Liquid or gas pressure in tanks	The model is simply conformable to reality; fixed system of pressures for a given level, depending on the structural form.	Considered in exceptional cases (effect of a motion of the filling body, hydraulic gradient in an earth dam, etc.).	As the forces applied depend directly on the structural form, the form will be commonly selected so as to get forces balanced advantageously enough;
Pressure of stored solid materials	System of wholly or partly free pressures, which can depend on the structural form (silos).		
2 - ACCIDENTAL Vehicle impact (car or truck, boat, plane, exceptionnally train or others)	Two cases, according to whether the forces are applied directly or not to the structure : . first case : the forces are horizontal or almost horizontal (except in the case of plane impact), more or less free in position and direction, . second case : forces are fixed (for instance, applied to the fastening point of a barrier)	Usually neglected	The models and their consequences depend on the selected procedure as regards safety against this possible danger.
Vehicle at a strictly forbidden place	Unique, highly simplified system (single vehicle), derived from the system of variable traffic loads.	Usually neglected	
Explosion	Special, usually complex model, which defines a partial destruction of the structure and may include uniform dynamic pressures on the non-destroyed parts.	They are due to the forces developped at the breaking points of the destroyed parts and to their fall. Often neglected despite their importance.	The model selected is conventional, with a view to selecting a robust structural form.

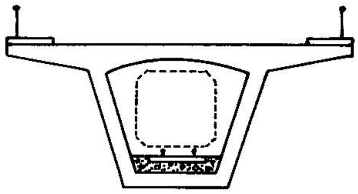
8. INFLUENCE OF LOADING MODELS ON THE FORM SELECTION.

It can be observed that m.m.l. as a whole, in spite of their large diversity, are introduced into the designs through a very short number of model types. Thus it is not surprising that the variety of structural forms should not be due to the variety of m.m.l. The diversity of forms is mainly derived from the other factors, notably the diversity of constraints of all natures, but these constraints are often connected to the existence or the magnitude of m.m.l.

Sometimes, for instance, its being not possible to introduce loads on areas with any disposition whatever with respect to one another, the selection of forms will be severely restricted.



instead of



A certain diversity of forms can also be brought directly by the different orders of magnitude of these loads (case of foot-bridges, road-bridges, rail-bridges, above mentioned), or even, exceptionnally, by the variation in magnitude of the modelized load, according to whether such magnitude is or not degressive as a function of the loaded area.

8.1 Case of variable loads, mainly vertical.

8.1.1 All models of principal loads are fairly identical : distributed loads uniform and concentrated, almost static, vertical downwards, intermittent, free.

The existence of free concentrated loads leads to design bi-dimensional structural parts (slabs, or including slabs and possibly ribs). According to the order of magnitude of the loads, to the spans, etc.,either the role of these parts is restricted to distribution, or they enact as principal girders. The heavier the loads, the more solid the forms.

8.1.2 Loads guided with accuracy seem rather exceptional; this, however, is the case of railway loads.

In this case distribution slabs are sometimes more or less completely abandoned, as in the case of certain industrial loads. In developing countries, the floor slab of certain road bridges is even sometimes performed by two lines of separated boards, though road loads are not guided accurately.

8.1.3 An intermediate case very frequent, even almost general, is the case where different natures of loads are systematically applied to distinct areas, perfectly determined. Such separation may lead to distinct bi-dimensionnal structural parts. When there is any doubt on the perennity of such separation (for instance, a cycle track may be incorporated some day into the neighbouring carriageway, even if the traffic are materially separated originally), preference is given to a common bi-dimensional part.

8.1.4 In a building where a dynamic working load is fixed (for instance, weight of a turbine), it may be advantageous in certain cases to disconnect completely its support from the building structure. This prevents the transmission of the dynamic effect to the whole structure, and retains the possibility of suppressing, through a restricted alteration, resonance with the foundation ground.

8.1.5 Following these choices, the other parts of the bearing structures are usually placed under (sometimes beside) the bi-dimensional structural parts, therefore rather freely with respect to m.m.l. It will be attempted, as far as possible, to select a structural form reducing distribution action-effects in the bi-dimensional upper parts to moderate values.

In many cases, the structure has two principal directions, and the choices of forms in longitudinal and in transverse directions may be separated, even in a single structural element.

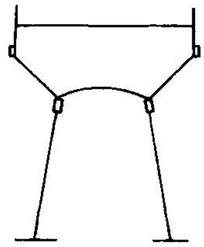
8.1.6 Secondary forces, with completely different directions, are sometimes not negligible in the selection of forms, mainly as regards supports. But they are often covered by wind, seism, accidental actions, etc., and have therefore no direct influence on the structural form.

8.2 Non-vertical pressure of solid or liquid materials.

This is mainly the case of dams, tanks and silos.

In these structures, the pressures of solid and liquid materials are distributed and applied to each point. Therefore a bi-dimensional envelope is constituted, which here again is an important part of the structures.

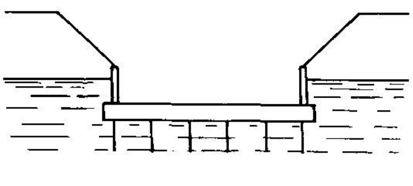
For the general balance of forces, the fact that they depend on the form of the envelope and are generally due to gravity leads, very often, to give the envelope and the structure itself a revolution form with vertical axis. The meridian line can usually be selected rather freely, and forces are balanced at the changes in direction through belts. Trying to get a proper balance of internal forces in various parts leads to the traditionnal mushroom-shape of tanks on top of towers.



However, in quite a number of cases (for instance, in canal bridges), functional, geometrical, or other constraints may lead to quite different forms, or even impose one form.

In the case of medium or high pressure gas tanks, the smallness of gravity forces as compared to pressures, and the pressure magnitude, lead logically to the spherical form as optimum form.

An example of a particular structure is constituted by shaft linings, which withstand occupancy or traffic loads inside, and water pressures, more particularly upwards, outside. These structures are subjected to important functional constraints. Moreover, its being impossible to provide supports as regards uplift, the upward force must be balanced through a ballast. Thus the loads are balanced locally, and action-effects are too small to exert any additional influence on the form selection.



8.3 Accidental actions.

The part they play in the form selection cannot be neglected; it is more diversified than the part played by variable actions. Their influence depends on their modelization, which depends in turn on the selected safety procedure (see above § 3.2). The selection of such procedure interacts with the selection of the form.

In all cases the degree of safety with respect to such loads is rather small; forms must therefore be selected with a view to reasonable possibilities of rehabilitation. It is sometimes advisable, with this end in view, to discard wholly welded metal structures, because the replacement of a damaged part would be very difficult, due to their form and design.

8.3.1 The treatment through structural design is analogous to the treatment of variable actions, with analogous consequences on the selection of the structural form.

- In the case of very free accidental loads, the forms are usually more solid than they would have been otherwise, but they are not, as a rule, altered fundamentally. Furthermore, it is generally thought useless to go to much expense in order to take accidental actions into account.

- In the case of more or less "fixed" accidental loads, strong structural parts must be provided at the estimated level of application of such loads.

But the other safety procedures with respect to such actions may exert very different influences upon the structural form.

8.3.2 Thus the control of these actions can exert a notable influence on the selection of a form, as shown by the following three examples :

- addition of a spillway to a dam,

- erection of the roof of a hydrocarbon tank, very close to the liquid surface, in order to prevent the accumulation of large amounts of gas, apt to explode,

- addition of equipments intended to deaden and localize impacts (barriers, guard rails, protective frames, pile clusters).

In certain extreme cases, for instance when an island is built around a bridge pier to protect it from ship impact, equipment also can be considered as an additional structure.

8.3.3 Even when danger is admitted, necessary endeavors to restrict the consequences of the accident (certain explosions or impacts) lead to select strong structural forms, apt to allow for various redistributions of load-effects after the accident. This selection is linked to the selection of a particular partial model of destruction, such as mentioned in section 7.

This model, in turn, is linked to the selected form. Thus, in a gunpowder factory, preference is given to a lightweight roof topping heavy walls, so that, in the event of an explosion, the damages are concentrated in the roof.

Robustness as a safety procedure is the object of a detailed analysis in the Structural safety Manual (C.E.B. Bulletin 128, paragraph 11.8).

8.4 Loads due to supports and foundations.

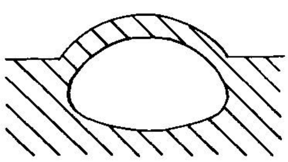
They are as a rule effects of other actions, not independent actions. But, whatever these other actions, human activity interferes specifically with them, through geometrical options, which often have very important influences on the structural form, since the function of structures consists primarily in transferring to supports and foundations the loads applied to buildings.

When such choices are made, the forces applied by the supports to the structures and reciprocally become fixed or almost fixed. The forms of the supports and of the supported structure may then be selected in such a way that fairly direct transfers of loads up to the foundations are obtained.

9. PARTICULAR PROBLEMS OF RELATIONSHIPS BETWEEN m.m.l. AND SELECTION OF THE STRUCTURAL FORM.

9.1 Case of certain permanent loads :

It was stated in paragraph 2.3 that the principal object taken into consideration would consist in the influence upon the selection of structural form of such m.m.l. as constitute data of the form selection; in the other cases, form selection and the corresponding m.m.l. interact, as is the case, in particular, of structure self weight. Such is the case also for a permanent load applied to the structures, during erection stages notably. Thus for tunnels under mountains, their shape and building procedures reduce the earth pressure applied to the inner covering with respect to its possible magnitude, to a considerable extent.



It is also necessary, sometimes, to create entirely artificial permanent loads, in order to carry out a selected form; the top of a flexible metal duct, for instance, must be loaded on backfilling, to prevent grave deformations of the duct, leading to collapse.

Inversely, in the case of settlement of mining ground, it may be advisable to contrive a flexible form, apt to resist imposed deformations.

9.2 Loads coming from maintenance works.

As well as building works, the works of maintenance of buildings give rise to application of man-made loads. Both lead to situations different of the durable situations; from our present point of view, this means that, at different times, the structures must withstand loads different in nature and in layout. The fact that several such situations must be taken into account leads to conclusions consistent with those obtained in taking free actions into account, with respect to the selection of structural forms.

10. CONCLUSION : LOGICALITY OF THE SELECTION OF THE FORM AND m.m.l.

The logicality of the selection of the form is quite complex : the data, constraints, and reasons to such a selection are very numerous and diverse; they interact upon one another and on the choice itself (sole, or almost sole decision) to lead to the so-called design (more precisely in French : la conception)

In this logic, the place of m.m.l., though far from negligible, is often rather modest; at any rate, they are not a major element of the diversity of forms. In this selection, m.m.l. do not intervene directly as a rule, but through their models and the designer, who according to the cases enjoys very unequal degrees of freedom with respect to the actions themselves.

11. ACKNOWLEDGEMENTS.

The authors wishes to thank Mssrs. G. DARPAS, N. ESQUILLAN and R. PERZO, whose ideas contributed to the elaboration of this report.